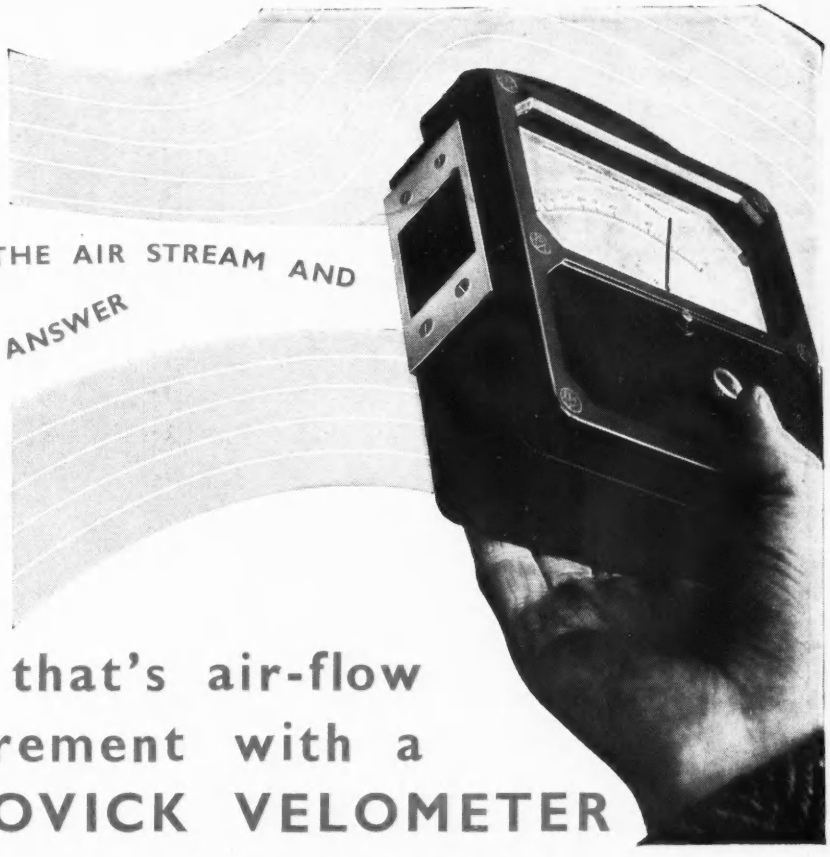
The
ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XII No. 12. DECEMBER, 1951



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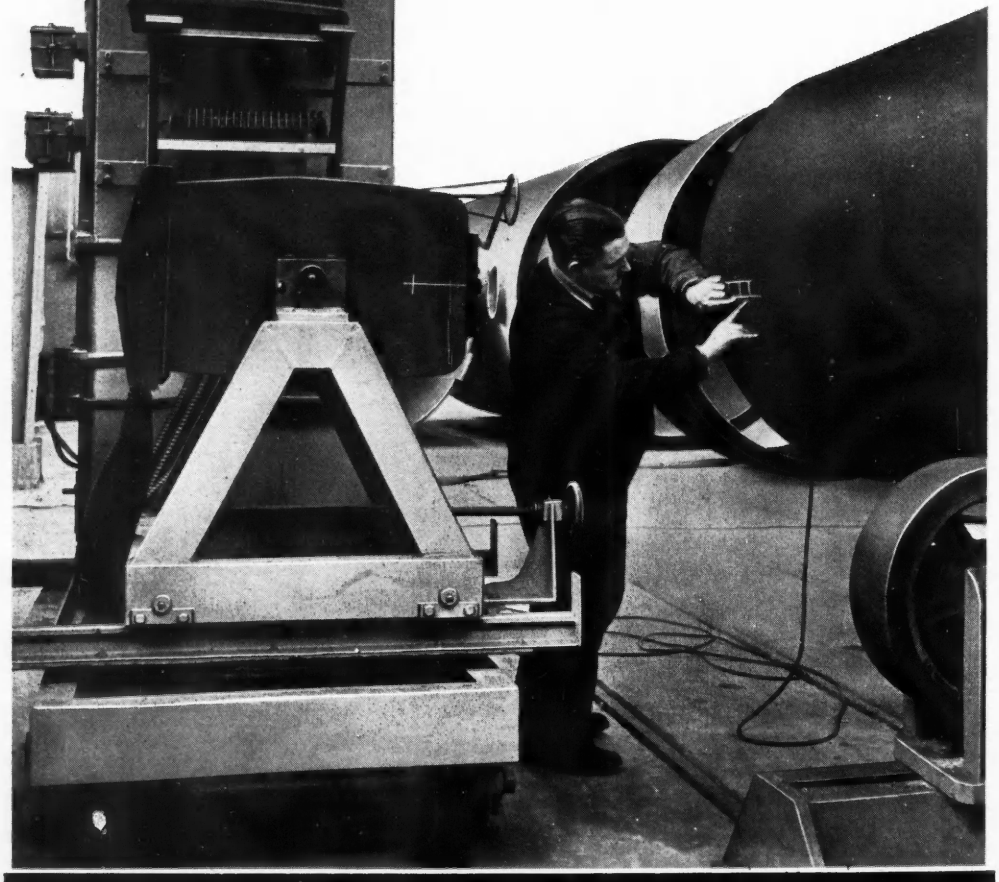

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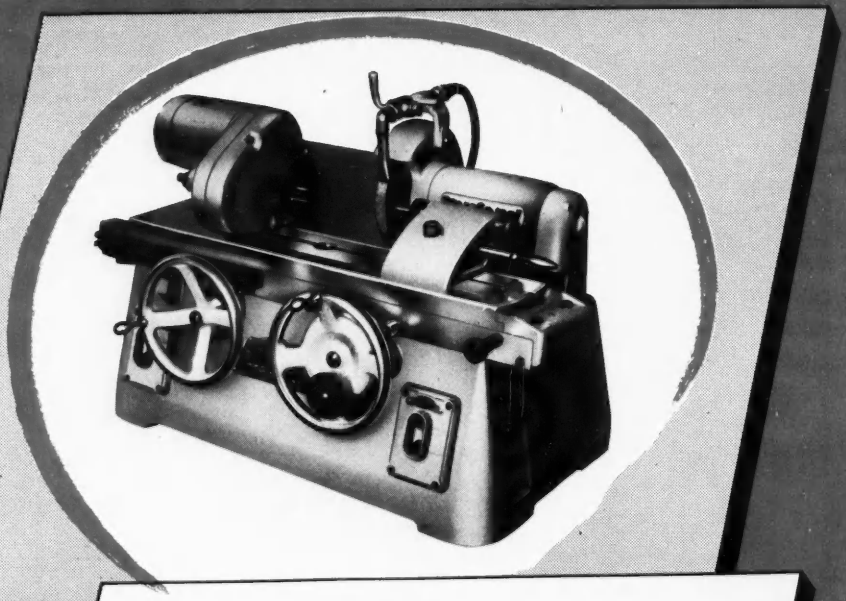

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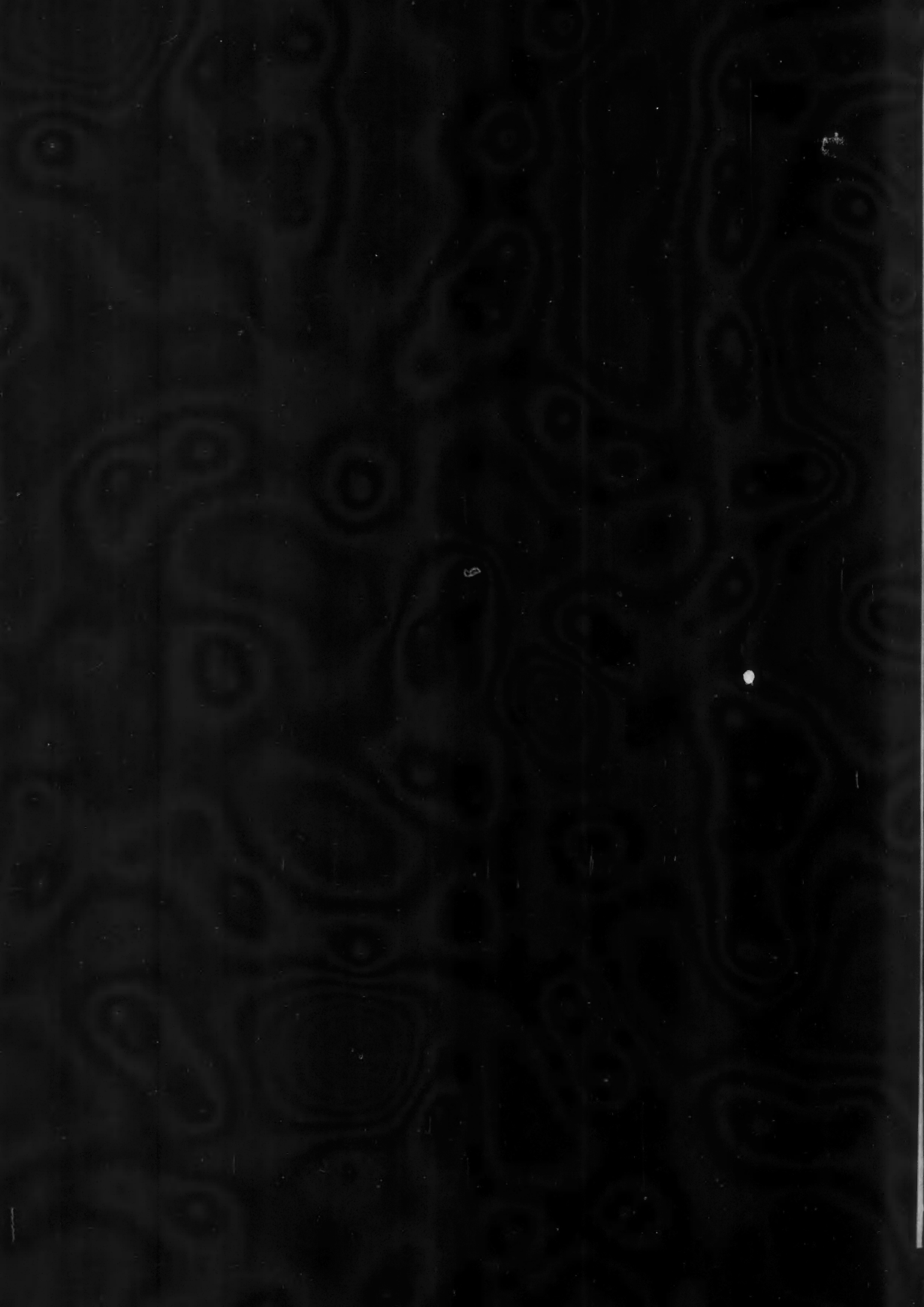

THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *ELECTRIC ARC SOLDERING*

A most interesting and promising method for joining studs or bolts, etc., to workpieces of the same or different material by means of an electric arc has been perfected. To the end of a metal stud to be soldered to a workpiece a small amount of solder and flux is applied. The stud is held in a chuck connected to one terminal of a source of electric current. The other terminal is connected to the workpiece to which the stud is to be soldered. The stud is then brought into contact with the workpiece so that the electric circuit is closed. The circuit, however, also contains the coil of a solenoid which pulls the chuck away from the workpiece upon closing of the circuit. This interruption of the current results in the occurrence of an electric arc which heats the workpiece locally, melts the solder, and at the same time projects the molten solder against the workpiece. In order to confine the heat and to prevent the access of air to the point concerned, a porcelain ring is placed around the end of the stud. A device is also provided in the electric circuit which makes it possible to control the delay period between closing and breaking of the circuit. As soon as the magnetic pull of the solenoid has ceased, after breaking of the circuit, the chuck is pulled back by a spring into its original position so that the stud is thrust into the pool of molten solder, thus completing the soldered joint. It is reported that this method has proved eminently suitable for the soldering of copper cables to rails for bridging rail joints. In this application, the low temperature required for the soldering process is of special advantage insofar as it does not lead to grain growth and mechanical weakening of the copper or to local air hardening of the metal of the rail.

● *CONTINUOUS CASTING AND WIRE ROLLING*

Following, as it does, upon the recent news of the successful operation of a pilot plant for continuous steel casting, the proposal of an automatic and continuous process for directly obtaining rolled wire from molten metal may well be indicative of coming profound changes in metallurgical engineering. Briefly, the inventor of the new process proposes to cast a continuous bar from the liquid metal by pouring the latter continually into a triangular groove cut into the peripheral surface of a rotating drum. This groove is closed over about half the circumference of the drum by an endless metal belt running over an idler of slightly smaller diameter, arranged near and slightly higher than the drum. Pouring takes place at the upper point where the oncoming belt contacts the drum, and removal of the solidified bar takes place at the lower point where the belt leaves the drum. In order to ensure complete solidification within a minimum of time, the drum is cooled by circulating water. A wedge-shaped slide is provided at the point where the solidified bar is to be removed from the drum. From this point the bar is then led to a number of rolling mills, where it is rolled into round shape and reduced to the required diameter. It is stated to be of the utmost importance to ensure that the liquid metal flowing from a nozzle into the groove will always be free from oxides and slag. This is to be achieved by the use of an induction furnace, whence the constant stream of metal is passed through a refractory pipe to the nozzle. This flow is enforced by electrodynamic pumping action known as "pinch" effect and produced by the simple expedient of passing a current of high amperage through the molten metal.

● *ONE-COAT PORCELAIN ON STEEL SHEET*

A process has been devised which, according to the claims of its inventors, produces a single-coat porcelain enamel which is non-chipping and non-cracking, and yet does not require the use of a special high-priced grade of enamelling sheet. This process, therefore, not only eliminates the ground coat which has been customary in porcelain enamelling, but also produces a sheet that can be sheared, sawed, drilled or punched without the enamel chipping-off or cracking. When the sheet is dealt a heavy blow, it bends and the enamel bends likewise. The total thickness of

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the new one-coat enamel approximates to 0·004 inch, which is about half the thickness of the ordinary two-coat porcelain enamel. It is this thinness which, combined with a high degree of adherence, serves to explain the flexibility of the coating. The new process would appear to enable considerable savings to be made both in materials and in labour. By applying only one coat instead of two, a smaller quantity of materials is needed. Moreover, the elimination of the customary ground coat dispenses with the need for cobalt. The need for applying only one coat of enamel instead of two or more will obviously reduce labour cost, and as only one coat need be fired and not two, the fuel costs will be correspondingly reduced. The sponsors of the new process therefore believe that it will prove competitive with organic finishes. It is reported that the process has already been introduced on a commercial scale.

● *OSCILLATING BEARING WITH MINIMUM FRICTION*

In small mechanisms of various kinds, including control gears and governors, bearings are frequently required to combine a relatively high load capacity with minimum bearing friction. This applies, in particular, to control gear of the type in which the actuating force is small. For many cases of this kind, small size and miniature ball bearings would appear to be suitable; unfortunately these have the disadvantage that their starting friction, which may be of decisive importance, is still larger than can be permitted in many cases. Certain bearings of this type have static friction moments of the order of 1/10 cm-gr which still may be ten times too large. The problem of providing a ball bearing of minimem friction can be solved by the simple expedient of cyclically oscillating the outer ball race of the bearing so that static friction is largely replaced by the smaller dynamic friction. The design of a bearing for oscillation of the outer race is a comparatively simple matter, and presents no intrinsic difficulties. A small electric motor needs, of course, to be provided for driving the oscillating mechanism, but its power requirements will rarely exceed a few watts. The angle of oscillation will be chosen as 10 to 30 deg., according to specific requirements. The oscillations will, of course, produce a torque acting upon the shaft, but as subsequent oscillations produce opposing torques, their sum total will be zero. Admittedly, when the shaft is rotated in one direction by the forces of the mechanism of which it forms part, there will be a residual torque due to the oscillations, but this will still be smaller than the static friction torque. Where alternating current is available, an electromagnet system can be used to induce synchronous oscillations by making the bearing oscillatory by means of a spring to give the system a natural frequency coinciding with the network frequency.

● *STROBOSCOPIC TORQUE INDICATION*

There exist many cases where a simple and inexpensive device for the rapid and reasonably accurate measurement of shaft torque is required. Brief reference to the recently published description of a torque indicator of the stroboscopic type will, therefore, be of interest. Indication by torsional displacement is produced by a helical spring of suitable stiffness which is placed between two coupling flanges and transmits the torque. The latter will thus be indicated by the mutual angular displacement of the two coupling halves, which can be read off on a scale provided on the periphery of one of the flanges, the other flange carrying a pointer. By illuminating the scale with a stroboscopic flash of light, it can then be read off during rotation of the shaft. For this purpose, one of the coupling flanges is provided with a contact which closes the circuit of the stroboscope lamp as the scale on the flange passes under it. Reduction gear losses can be ascertained by measuring both input and output torque. It is even possible to transfer the readings of the output torque indicator to the input indicator or *vice-versa* by placing two stationary transparent scales over the two coupling halves of the latter and providing a second scale on the output half of the coupling, taking into account the gear ratio. By illuminating the scales first by operating the stroboscope lamp circuit by the contact of the input indicator and then by the contact of the output indicator, the relative torques or the gear efficiency can be read off directly.

● *ACCELERATING DIFFUSION-TYPE IMPREGNATION PROCESSES*

In spite of the considerable efforts made in recent years to achieve the large-scale introduction of chromium diffusion processes into industrial practice, successes have so far been only sporadic. In order to be able to make such processes competitive with other methods of surface treatment or with clad materials, low treatment cost is, of course, essential. Recent investigations have therefore been focussed upon the shortening of the processing time required, which, in certain cases, is quite considerable. Quite generally, the speed of diffusion processes is an exponential function of the process temperature, but further increases above the temperatures now in use do not appear possible. It has now been proposed to speed up diffusion by loosening the lattice structure of the material by applying high-frequency currents to the surface of the piece to be treated. In fact, it is claimed that even the passage of electric current of network frequency causes a marked speed-up of the rate of diffusion. Considering the presence of a marked skin effect with high-frequency currents which confines heat development largely to the surface of the work-piece, it is thought possible that, by using high-

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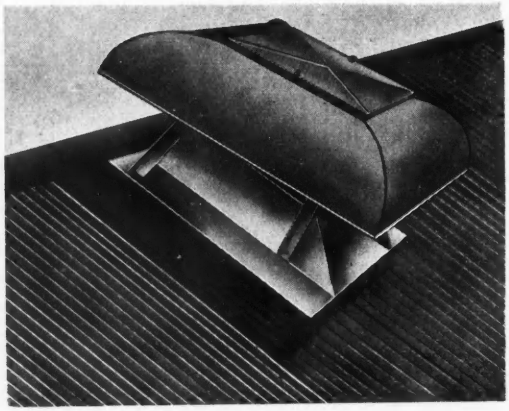

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frequency currents, large pieces can be diffusion-treated without requiring heating throughout, as is now necessary. Should such a process prove feasible, a way would be open to the processing of bulky pieces by short-time diffusion treatment without affecting the internal structure of the piece.

● *LOAD-SUPPORTING CAPACITY OF VIBRATING OIL FILMS*

A significant characteristic of fluid films which is associated with their load-carrying capacity has been uncovered in a recent study devoted to the non-steady load capacity of fluid wedge-shaped films. This study has definitely established the fact that thin films strongly resist being squeezed out from between metal surfaces, especially if the boundary surfaces are approaching each other at high velocities. In other words, the non-steady-state characteristic of the motion of the bounding surfaces of fluid films is responsible for their ability to support relatively great loads. Conditions of this kind exist in numerous engineering applications involving fluid films, such as the lubrication of various bearings and gear teeth. It is a fact that the steady-state theory never has been able to account satisfactorily for the relatively large loads which bearings and gears carry every day. This theory indicates unreasonably thin film thicknesses for these members when used with heavy loads at low speeds; often, these thicknesses are much smaller than the surface roughness of the metal bounding surfaces. Neither can the theory account for the loads which are carried successfully in high-speed gearing such as in certain turbine gear units. In such cases, the period of mating is very short, and the whole lubrication phenomenon is in a non-steady state, without question. It is highly probable that the facts discovered now partly explain why such gears actually work. The experimental data leading to the establishment of the new theory were obtained on a device in which a fluid wedge-shaped film was formed by dragging oil between two disks rotating in opposite directions. This wedge was alternately thick and thin by vibrating one of the disk shafts at a frequency of 425 cycles per second.

● *MEASURING VERY SMALL DIRECT CURRENT VOLTAGE*

For the measurement of direct current voltages as small as 10^{-6} volts, a method has been developed in which the direct current voltage to be measured is supplied to a carbon-type microphone which is exposed to sound of constant frequency and amplitude. The alternating current voltage into which the pulsating current is transformed in an amplifier which has a considerable rate of gain is then passed to a moving coil instrument *via* a rectifier. It is reported that this method has very little inertia, so that pulsating direct current voltages may be measured, provided the frequency of pulsation is smaller than the frequency of the sound to which the microphone is exposed. By using special types of microphones sensitive to ultrasonic vibrations, and by installing an ultrasonic generator in front of the microphone, direct current voltages of high pulsation frequency can be measured. Because of the comparatively low ohmic resistance of the microphone, the method may be used for measuring direct current sources of low internal resistance, as, for instance, the voltages produced by thermocouples or by photocells. It is claimed that it was thus found possible to measure the voltage generated in a copper-constantan thermocouple by approaching a finger some 2 inches near the cell or breathing in the direction of the cell from a distance of one foot. A modified arrangement has also been developed by the same research scientist, in which the ordinary microphone is replaced by one of the condenser type. While the sensitivity of this circuit is limited to the measurement of voltages of not less than one-hundredth of a volt, it has the advantage of high internal resistance so that no power loss is involved.

● *NEW TYPE OF STRUCTURAL STEEL*

In view of the disastrous consequences which may result from the failure of a bridge structure, engineers and metallurgists alike are hesitant to employ unfamiliar steel compositions in bridge construction. This attitude is particularly marked in the case of welded construction, and the fact that a new steel has been used in a recently completed bridge across the River Rhine would indicate a high degree of confidence in the new product. According to the meagre information available, the new material is a structural steel of high strength with a manganese content of 0·9 per cent. An interesting feature is that, contrary to earlier German tendencies, no copper is added as alloying material; nor is chromium or molybdenum present. A novel deoxidising method is claimed to be responsible for the improved quality of the steel. As regards the bridge itself, the report states that its centre span of little less than 700 ft is the widest span in the world for which welded plate girders have ever been used.

● *COMBATING EXHAUST NUISANCE*

There is no doubt that the discharge of noxious exhaust gases by motor cars constitutes a most undesirable feature of modern traffic, especially in crowded cities. Yet it is accepted by the public with the same indifference as the smoke nuisance. In the case of the latter, a certain degree of public reaction has finally manifested itself in recent years, resulting in the control of smoke emission from power plant stacks. Whether the public could be aroused to insist upon some sort of exhaust abatement, however, appears highly doubtful, especially as the suppression of the exhaust

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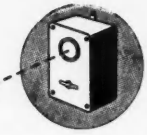

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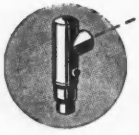

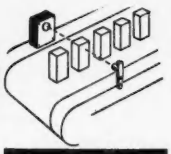

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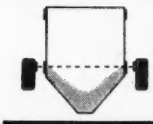

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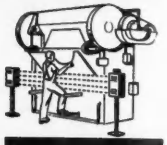

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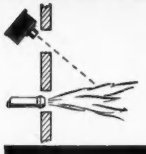

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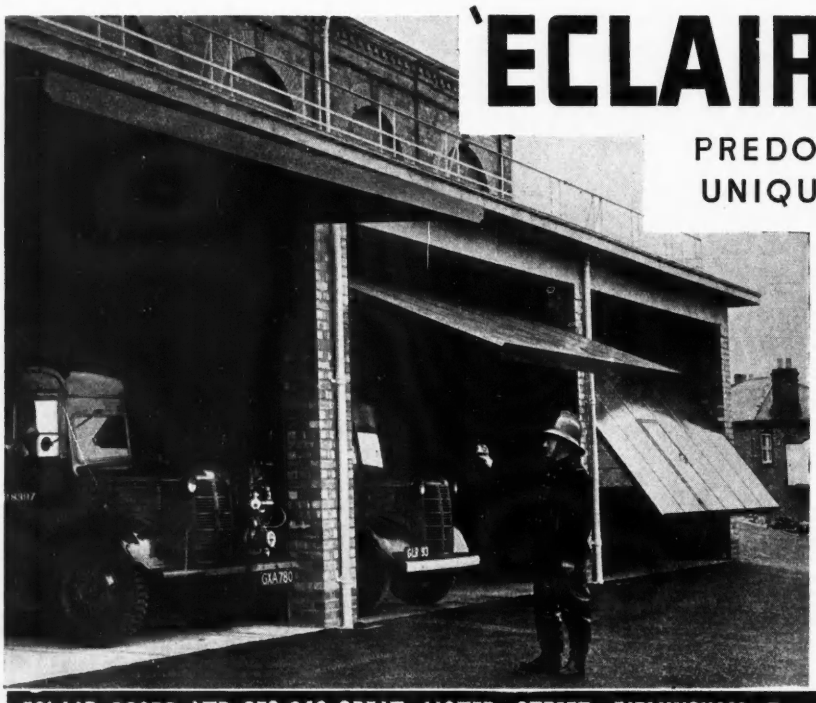

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nuisance would entail a perhaps not inconsiderable expenditure by the car owners. A recent proposal which may deserve more than casual consideration envisages the saturation of the exhaust gases with water vapour in a gas washer of some kind. The moisture-laden gases would then be passed through a small air-cooled condenser from which the water droplets entraining the noxious constituents would be discharged upon the ground. Needless to say, such a system would require occasional re-filling with water, and considering the corrosive nature of the discharge, the apparatus would have to be built of corrosion-resistant materials.

● *GROWTH OF WHISKERS ON METAL*

An investigation of troubles experienced with the operation of telephone equipment has drawn attention to a strange phenomenon, namely the occurrence of filamentary growths, or " whiskers," on metal surfaces, particularly on parts shielded from free circulation of air. This phenomenon had been observed previously on the leaves of cadmium-plated air condensers of military equipment during the early part of the last war, but had then apparently been considered a characteristic of cadmium plating. Systematic research, which was initiated in an attempt to determine the mechanism of growth, has now definitely established the fact that whiskers may grow not only on cadmium plating but also on other metals. The whiskers are not normally found on parts for some time, often months, after having been electroplated, but it has been possible, by increasing the ambient temperature, so to accelerate their growth that they will develop in a matter of weeks. Examination of the whiskers at a magnification of 20 diameters showed them to be quite flexible and to move in the slightest air current. In general, individual filaments tend to grow perpendicular to the plane of the metal surface, but radiating clusters of fibres at various points have also been observed. Whisker growth is not limited to electroplated parts, but occurs also on solid metals, as well as on surfaces metal-coated by various methods. Moreover, the growths may develop under conditions of relatively low humidity and in atmospheres in which there are, at most, only traces of organic material. The whiskers are not compounds but are metallic filaments in the form of single or twinned crystals. The mechanism of their growth remains yet to be explained.

● *NEW ELECTRICAL CONTACT MATERIAL*

As electrical contact material, silver is finding a very wide range of applications, owing to its excellent electrical conductivity and its relatively low cost as compared with other contact materials, such as platinum and the like. Unfortunately, silver contacts suffer from the disadvantages of welding or sticking and coning and cratering. These drawbacks prevent the use of pure silver contacts where heavy currents are involved, and more suitable alloys including silver alloys are used instead. It has now been found that silver contacts can be greatly improved by adding a certain amount of tin oxide in finely divided form to the silver. Contacts of this composition are conveniently manufactured by methods of powder metallurgy, that is, by compressing and sintering a powder mixture of silver and tin oxide, in which the tin oxide may amount to 0·1 to 50 per cent by weight according to requirements. Electrical contacts made in this way and containing 90 per cent silver and 10 per cent tin oxide have been tested under severe operating conditions, it is reported. In one such test, silver-tin oxide contacts were fitted to a solenoid-operated plunger-type relay breaker designed for a contact pressure of 300 grams. The actual test involved making and breaking a load of 75 amps, at 30 volts d.c. at the rate of 68 switching cycles per minute, until 50,000 cycles had been performed. Inspection of the contact surfaces after the test revealed only a slight roughening of the surface, cones and craters being absent. Equally good results are reported for a test covering 50,000 switching cycles at the rate of 50 cycles per minute with an amperage of 200 A at 30 V. The contacts used for the latter test were found to be capable of breaking a current of 800 A for a total of fifty times.

● *EVAPORATIVE COOLING OF HIGH-SPEED TOOLS*

The use of cemented carbide cutting tools has made it possible, in certain cases, to employ cutting speeds as high as 5,000 fpm and more, so that the chips are removed in a red-hot state. Unfortunately, the occurrence of such a high temperature is reflected by a deterioration in surface quality of the cut, diminution of the strength of the material of the workpiece, the creation of residual surface stresses, etc. The cutting edge of the tool, of course, is also adversely affected and tool life is considerably shortened. In order to intensify the cooling effect of the cooling medium, it has been suggested to resort to evaporative cooling. In one form of evaporative cooling, a mist consisting of an air-coolant mixture is blown from a nozzle upon the cutting point. The coolant mixture consists of compressed air and water, to which a small amount of cutting oil has been added. The oil precipitates upon the workpiece after evaporation of the water and provides a film which protects the surface of the workpiece against corrosion. The vapour generated is removed through an exhaust hood.

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.

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Aircraft Nuclear Propulsion*

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1. INTRODUCTION.

In spite of the restrictions placed upon this discussion on security grounds, the principles underlying nuclear-powered flight, some possible methods of achieving it, and some problems which are involved may be freely outlined. Before starting this discussion, however, we should pause a moment to answer the question, " Why do we want to fly an aircraft on nuclear power ? "

Many years ago, Breguet set down the formula which states that the range of an aircraft is proportional to its lift-to-drag ratio and to the efficiency with which its propulsive system works, and inversely proportional to the weight of fuel consumed per unit of work delivered to the propulsive system. Any decrease in the specific fuel consumption obviously leads to increased range. Because of the ingenuity of the designers of aircraft and engines, the Breguet formula is scarcely of more than academic interest in these days. Devices such as accomplishing most of a flight slowly and using high speed only at critical times, refuelling in flight, and discarding not only the fuel tanks but also the lifting surfaces which support them as soon as they are empty, all have been seriously proposed or practised and operate greatly to increase the range of modern aircraft. However, it is no deprecation of our heavy bombers to say that even more range would be desirable, particularly if it can be coupled with high speed. This is the point at which the nuclear-propelled aeroplane comes into the picture. One pound of uranium-235 will liberate heat on undergoing fission equivalent to the energy liberated by burning 1,700,000 pounds of petrol. It is at once evident that if a means can be found for converting the energy of nuclear fission into thrust, aircraft can fly for very long times on very small amounts of fuel. Because of the enormous amounts of energy available from a small amount of fuel, highly efficient utilization of this energy would no longer be crucially important. Thus, specific fuel consumption could be allowed to worsen somewhat if this were desirable in order to make some other feature of the power plant easier or better.

Although the basic superiority of nuclear fuel over chemical fuel is thus superficially stated as a simple ratio of 1·7 million to 1, the implications and complications of this fact are extremely varied and far-reaching. For example, a nuclear aircraft could encircle the globe many times without stopping, it could fly entirely around the world at local midnight, accomplishing the entire circuit in darkness and with the lower vulnerability which night flying confers. Careful husbanding of fuel, programming of flight speed and altitude, and closely timed flight plans would become unnecessary. Such an aeroplane could fly at its maximum speed and at any altitude over its operating range for all or any part of its mission and still be perfectly certain of having enough fuel to return to its home base by any route whatever. A nuclear-powered aircraft could possible stay aloft for many days. It would be limited only by the freedom of the aircraft and power plant from breakdown and by the ability of the crew to endure long hours of flight and exposure to nuclear radiation.

*Condensed from an address to the Chicago Section of the Institute of the Aeronautical Sciences, October 4, 1951.

2. PRINCIPLES AND SUGGESTED METHODS

One of the basic principles of nuclear energy is that the energy of fission is manifested as heat, that is, a nuclear reactor is primarily a source of heat which must be converted into thrust or into mechanical work in more or less conventional ways. Hence, in any nuclear power plant, whether it is for an aircraft, a naval vessel or for the generation of electricity on the ground, there will be a reactor and heat machinery. In the aircraft, the heat machinery is the propulsion system. Also, and somewhat unpleasantly, the reactor is a source of radioactivity; hence, there must also be a shield of some type or other.

PROPULSION MACHINERY

There is scarcely a single type of aircraft propulsion machinery which has not been proposed for incorporation in a nuclear power plant. One obvious proposal is that propellers be used, driven by turbines which are, in turn, run by expanding through them vapour such as steam, heated in the reactor, or air heated in the reactor. A variation of this scheme would be to extract the heat from the reactor by some liquid coolant other than vapour or air and transferred to the vapour or air in an external heat exchanger or boiler. Another fairly obvious proposal is that the reactor should directly or indirectly take the place of the combustion chambers of a conventional turbo-jet engine. Here, again, the heat might be extracted from the reactor directly by the air or indirectly by other coolants, such as liquid metals, and transferred to the air outside the reactor. Ducted fans driven by turbines, operated in turn by vapour or air heated in the reactor, have been suggested. Obviously, the reactor might also take the place of the combustion apparatus in a ram-jet propulsion system. It has also been proposed that a compressor-jet type of propulsion system be used, with the compressor driven by vapour or hot air from the reactor and the heat supplied to the air by a heat exchanger through which the reactor coolant passes. In all cases, except that of the ram-jet and other direct air cycles, it is required that heat be transported in a coolant from the reactor to the propulsion machinery. In making a choice among the various types of propulsion machinery, the designer must perform detailed and careful analyses of many different possible combinations. Some of the problems which confront him are so obvious that they may be mentioned here. For example, if a propeller-type propulsion system is chosen, the hot fluid from the reactor must be piped to the turbines which drive the propellers ; these, in turn, must be mounted on the wings. Thus, each propeller must be provided with its own reactor, or hot fluids must be piped around the aeroplane from a central reactor heat source. Any reactor coolant will undoubtedly become somewhat radioactive in passing through the reactor, and this alternative hence is not attractive. On the other hand, providing each propeller with its own

reactor is not easy either, for two reasons. First, the weight of a reactor with its shield is very large ; more than one reactor and shield, therefore, is highly undesirable from a weight standpoint. Second, two reactors per aeroplane would require more than twice the fuel investment of one reactor and a low fuel investment per aeroplane is desirable, rather than a high one.

Reactor

The design of the reactor will be greatly influenced by the coolant chosen. However, the basic principle upon which the reactor operates is the same, regardless of the coolant. This principle is as follows : The reactor may be thought of as a more or less cylindrical body, throughout which a fissionable material such as uranium-235 or plutonium-239 is distributed. The reactor also contains passages for the flow of the coolant through it necessary for the removal of the heat and also usually contains a material which is called a " moderator." The reaction starts with the capture of a neutron by a nucleus of, say, uranium-235. Since neutrons are present in small concentration in the atmosphere everywhere, this serves to start the reaction. Immediately after capture of the neutron, the U-235 nucleus disintegrates with the liberation of two to three neutrons and 2 atomic nuclei (fission fragments), both smaller than the original nucleus. Most of the energy of fission is carried off by the fission fragments ; this energy is imparted to the material into which they are cast and appears as heat. Gamma rays and beta rays also are given off in the fission process.

The two to three neutrons given off are ejected into the body of the reactor and may undergo one of three different fates :—(1) they may escape from the reactor entirely and be captured outside it by some parasitic nucleus in the structure of the shield or its surroundings ; (2) they may be captured by some of the non-fissionable materials in the reactor itself ; and (3) they may be captured in another U-235 nucleus, following which additional neutrons will be given off. If we can design the reactor so that as many as about 40 per cent of the neutrons given off in fission are captured in other fissionable nuclei in such a way as to cause fission there, the reaction will continue indefinitely until the fissionable nuclei are used up.

The basic problem of reactor design is to reduce to acceptably low values the first two methods of loss of neutrons mentioned above ; that is, leakage from and parasitic capture in the reactor. Leakage may be counteracted to some extent by surrounding the reactor with a neutron-reflecting material such as graphite and beryllium oxide which scatters but does not capture the neutrons. Excessive capture of neutrons in non-fissioning nuclei in the reactor may be avoided by eliminating from the reactor atomic species which have a strong tendency to capture neutrons, i.e., have a high neutron capture cross-section. Unfortunately, it is not always easy to do this, because some of the materials which are most suitable for use as reactor structure, and without which the reactor will not support itself, have rather high capture cross-sections. These are thus poisons for the nuclear chain reaction, although essential for the mechanical stability of the reactor. Obviously, we may increase the fraction of the neutrons which are absorbed in U-235 nuclei by increasing the proportion of U-235 present in the reactor. Unfortunately, this increases the amount of fissionable material invested in the reactor, and since fissionable material is extremely precious, it is desirable to keep its investment to a low value. We usually, therefore, resort to the device of introducing into the reactor a moderator, which is an element of low atomic weight and low capture cross-section for neutrons. Because of its low atomic weight, a neutron striking it loses a relatively large fraction of its energy in each such collision. Because of its low capture cross-section, it does not capture many of the neutrons which strike it. After the neutrons are thus slowed down or moderated, their capture by the fissionable material in the reactor becomes much more probable, since the cross-section for capture of low-energy neutrons is higher than that for high-energy neutrons. Typical moderators are graphite, ordinary water, heavy water, beryllium and beryllium oxide. The control of the chain reaction is, in principle, exceedingly simple. One of the most direct means of control is to arrange an absorbing rod so that it can be inserted into the reactor or withdrawn from it. If the rod is withdrawn from the reactor, it will absorb a smaller number of neutrons than before. If, in its original position, the rod was absorbing that number of neutrons which made the reactor just critical (that is, neither rising nor falling in power) then withdrawal of the rods will create a slight excess of neutrons in the reactor and the power will begin to increase. If, for example, we withdraw the rod so that the fraction of the neutrons absorbed in fission is 0·1 per cent greater than before, then the number of neutrons in the reactor will increase by 0·1 per cent in each neutron generation. Since the neutron generation time is extremely short, the reactor will build up fairly rapidly in power in an exponential manner. When it is desired to stop this build-up, all that is necessary is to insert the control rod to its original position. Other methods of control have also been proposed. For example, in a reactor which has a reflector, removal of part of the reflector will allow the leakage of more neutrons than before. This will decrease the reactivity and constitutes a method of control. Also, removal of part of the moderator or of some of the fuel itself from the reactor will decrease the reactivity, and these expedients may also be used as control mechanisms.

It is evident that the control of the reactor is an important matter. Over-heating, if sufficiently severe, can cause accelerated corrosion, warping or even melting of parts of the reactor. Also, it is important that the reactor should not be operated without a flow of coolant through it, since this certainly will result in serious damage, if not destruction of the reactor.

Shield

Although most of the energy of nuclear fission appears as kinetic energy of the two fission fragments mentioned above, and this kinetic energy, in turn, appears as heat in the fuel elements, a substantial portion of the energy of a reactor appears as kinetic energy of the neutrons and as ionizing radiation, such as gamma rays and beta rays. The neutrons and gamma rays, if allowed to escape with complete freedom from the reactor, would make it necessary for human beings to stay at a distance of more than a mile from a high-powered reactor while in operation. Moreover, since the fission products themselves are radioactive and continue to emit gamma rays even after the chain reaction has been stopped, it would not be possible to approach the reactor very much closer than this, even after it had been shut down. It is clear that a shield must be provided.

The basic requirements of the shield are dictated by the two basic types of radiation which it is desired to stop. The neutrons are slowed down most effectively by light atoms such as hydrogen, and moreover are more easily captured after being slowed down. For this reason, an effective shield will contain light atoms such as hydrogen, which also is a good slow neutron absorber. Gamma rays, on the other hand, are degraded in energy and stopped best by heavy elements such as lead. It is clear, therefore, that a mixture of light and heavy elements will be desired. For a reactor which is to be mobile, it is important that the shield weight and dimensions be kept small. Hence, the materials put into the shield must be the best possible and must be arranged in the best possible fashion. The detailed solution of this problem is extremely complicated.

Another point of importance is that not only must the

shield prevent escape of radiation from the reactor to the desired degree, but also it must be capable of admitting and emitting the coolant which carries the heat away from the reactor. This means that ducts must pierce the shield, and we are then confronted with the problem of leakage of radiation through these ducts. Generally speaking, gamma rays and neutrons travel in straight lines. However, under certain conditions, they can be scattered or reflected around corners or curves. This confronts us with another difficult but interesting problem.

3. SOME PROBLEMS OF NUCLEAR-POWERED AIRCRAFT

It may be interesting to pose some difficult problems in addition to those mentioned above which confront the designer of a nuclear-powered aircraft.

Shield Weight

The shield will be the heaviest single object aboard the aircraft. Early published estimates of shield weight placed the minimum at 50 to 100 tons, without any provisions for removal of heat. From this, it is evident that a large aircraft will be required to carry a weight of this magnitude, even though the aircraft need carry little or no chemical fuel. To a first approximation, one may balance off the weight of the shield against the weight of the fuel load which would be carried in the large modern aircraft, since the shield and the reactor which it contains essentially replace the fuel load. The fuel loads of modern aircraft range up to the neighbourhood of 75 tons or more. However, every effort must be made to keep down the weight of the shield and the reactor. One obvious way to do this is to make the reactor small so that the shielded volume is kept small. This, in turn, restricts the amount of cross-sectional free flow area through which coolant may pass through the reactor, and increases the pressure drop. Moreover, as the reactor diameter decreases, it usually is found that more fissionable material is required. This is undesirable. There is, therefore, a balance to be struck between the benefit of small shield weights resulting from decreased reactor size on the one hand, and the disadvantages resulting therefrom in smaller free flow area for coolant flow and larger fissionable material investment required.

Balance and Structure

The existence of a large concentrated weight such as the shield and the reactor at one point in an aircraft makes it necessary to redesign the structure of the aircraft to accommodate this weight. Although large aircraft are designed for very large gross weights, this weight is usually distributed over the wing and throughout the fuselage. Concentrating the weight in the fuselage greatly increases wing bending moments and necessitates structural redesign in many cases.

Large Landing Weight

The very fact that only a small amount of the fuel is consumed in flight means that the gross weight of a nuclear aircraft will be approximately the same on landing as on take-off. First, the landing gear must be made strong enough to take the higher gross landing weight. Second, the landing speed is increased and there may be a change in landing attitude which possibly could require changes in the landing gear, or in tail clearance angle requirements.

Heat Transfer

The very essence of a nuclear power plant is the transfer of heat from the reactor to the propulsion machinery. The requirements for small size and high power density placed upon the aircraft reactor push the heat transfer designer to the limit of his knowledge. He must avoid hot spots in the flow system, he must have good flow distribution and he must know exactly how the power is distributed in the reactor so that he can supply the right amount of coolant to each part of it. Solution of these problems requires a great deal of detailed analysis and experiment.

Fissionable Material Investment

The desirability of keeping the quantity of fissionable material in the reactor small has been mentioned previously. However, the chain reaction will go in the reactor only so long as there is present a certain minimum quantity of fissionable material called the "critical mass." As soon as the reaction has consumed so much fissionable material that the mass drops very slightly below the critical mass, the chain reaction dies and cannot be started again without adding more fissionable material. Moreover, the products of fission remain in place in the fuel elements and eventually must be removed. This makes it necessary to remove the remaining fuel from the reactor, purify it and prepare it for reuse. The amount of uranium which may be tied up in the reprocessing activities may easily exceed that which is tied up in the reactor proper. Thus, the uranium investment is not simply the amount of uranium carried aboard the aircraft but also that which is on the ground in various stages of preparation for use. The question of recovery and reprocessing of the fissionable material is a matter for the chemist and chemical engineer, and is a whole new subject.

Radiation Damage

Inter-nuclear collision between neutrons and the nuclei of materials used as structures or as moderators in the reactor or between fission fragments and other nuclei result in dislocation of the nuclei with which collision occurs. While it is not definitely known how great an effect these dislocations have, it is known that the properties of the materials in which they have occurred undergo a change. Usually this change is in a detrimental direction. For example, a decrease in thermal conductivity may occur, thus making the heat removal problem even harder, or, other equally critical properties may deteriorate.

Some liquids or gases which might be proposed as reactor coolants are decomposed by radiation, and are hence not usable. Organic compounds are particularly susceptible, and even outside the zone of most intense radiation in the reactor ordinary lubricants turn tarry or even solidify. Lubricated machinery hence may not be used in such locations. Electrical insulation, on prolonged exposure to radiation, breaks down and disintegrates or loses its effectiveness.

There is here a large field of investigation, particularly in the physics of solids, where much work must be done in order to elucidate the effects of radiation damage on the materials which might be used in an aircraft reactor, or in radiation-exposed locations in the shield.

Escape of Radioactivity

It is evidently necessary to confine substantially all the radioactivity of the reactor within it. This imposes on the designer of the reactor another restriction. It is occasionally suggested that a nuclear aircraft will create a hazard to population in its vicinity. Inasmuch as the aircraft itself will carry a crew which must be protected adequately, persons at a distance will not be affected in any way.

Materials

One of the most important problems in reactor technology today is the finding and development of materials adequate for use in reactors which are proposed for production of power in one form or another. The combined effects of high temperature, corrosion by various coolants, radiation damage, thermal stresses,

and mechanical stresses can be extremely serious in some cases. The aircraft reactor presents these problems to an unusual and critical degree. For example, a difference of 100° F in permissible maximum reactor temperature can easily produce a 15 per cent difference in thrust output of the power plant. High-temperature materials are therefore a prime necessity. A corrosion-resistant coating on the reactor heat transfer surfaces a few thousandths of an inch thick may double the critical mass. A brazing alloy containing a few per cent boron (a strong neutron absorber) may put so much boron into the reactor that it cannot be made to go critical, and this particular alloy may therefore be entirely unusable. An alloy high in nickel may have good corrosion and high-temperature strength properties for use as reactor structure, but be so strong a neutron absorber as to be substituted by another alloy of lower nickel content and poorer corrosion and strength properties. The finding of materials adequate to withstand these conditions is a challenge worthy of the best metallurgists, ceramist or chemist.

4. OUTLOOK

In many respects, the propulsion of aircraft is an ideal use for nuclear energy. Here, to a higher extent than in any other application, the advantages of a highly concentrated source of heat can be used to good result. Although the goal of producing a nuclear-powered aircraft is an admittedly ambitious one, it is only such high-performance premium uses of energy which can today justify the consumption of as rare a resource as uranium-235 or plutonium-239. Moreover, it is inescapable that a development of this type has great military significance.

My belief is that our efforts to fly an aircraft on nuclear power will be successful. The difficulty of the task and the value of the result combine to form a challenge which is, in my opinion, unmatched.

SWITZERLAND

Some Aspects of Hydraulic Copying Devices

By R. CHIAPPULLINI. (From *Schweizer Archiv*, Vol. 17, No. 9, September 1951, pp. 268-275, 16 illustrations.)

The analytical treatment of various hydraulic systems has so far received little attention. The following article covers the development of several analytical relationships, a discussion of their practical implications and several new design suggestions. The analytical treatment proves the superiority of the symmetrical flow control system over the unsymmetrical pressure control system. The flow control system with an auxiliary pressure control valve is treated next. Finally, several suggestions are made towards eliminating the fluctuation of friction forces in the main control valve, in the linked feed piston and its piston rod, and in the linked slideways. This would reduce the inaccuracy at profile peaks, caused by the elasticity of the machine and of the oil, and by force fluctuations.

EXISTING hydraulic copying systems can be divided into two basic types:

(1) Systems having a feeler connected to oil ports, the oil flow to and from the feed cylinder being directly controlled by the latter, i.e., mainly by flow control and partially by pressure control, as in the Monarch lathe, see Fig. 1.

(2) Systems having a feeler connected to oil ports, the oil flow to and from the feed cylinder being indirectly controlled by the latter through throttling, i.e., mainly by pressure control and partially by flow control, as in Oerlikon and Fischer lathes, see Fig. 2.

The first system employs a pneumatic or hydraulic auxiliary motor (relay) to increase the sensitivity and accuracy of the whole system, the auxiliary motor operating on the principle of pressure-controlled throttling (Fig. 6). This auxiliary motor could also be incorporated in the second system. The sensitivity of both systems can theoretically be increased by mechanical transmission; in practice, however, this is not feasible as the movements are so small that they would take place within the initial stages of elastic deformation of the mechanical transmission elements. This would be particularly detrimental on reversals.

The main requirements of a hydraulic copying system are:

(1) High copying accuracy, even with the maximum possible speed components (v_z, v_y) and cutting forces.

(2) Good surface finish, even during the reversal of any feed component and during sudden fluctuations of cutting forces or friction forces.

DEVELOPMENT OF BASIC EQUATIONS

The following laws apply to the oil flow through sharp-edged piston valves as used in the systems under discussion:

$$V = 0{\cdot}106\sqrt{\Delta p} \quad .. \quad .. \quad (1)$$

$$q = 0{\cdot}637\, a\sqrt{\Delta p} \quad .. \quad .. \quad (2)$$

V = Flow velocity [m/sec]
q = Flow per minute [litres/min]
Δp = Pressure drop in valve [kg/m²] or [kg/cm²]
a = Flow section [mm²] = $s\,U$
s = Valve displacement [mm]
U = Valve circumference [mm]
S = Piston area [m²]
F_a = External piston force [kg]
γ = Specific gravity of the oil [0·9 kg/dm³]
g = Gravity acceleration [9·81 m/sec²]
ρ = Density of the oil [approx. 90 mass kg/m³]
v = Feed rate [m/sec] or [m/min]

Due to the two equal and adjacent ports in flow control systems as in Fig. 1, it is clear that:—

$$p_1 - p_2 = p_3 - p_0 = p_3$$

and, therefore, ignoring the piston rod cross-section,

$$p_1 = 2\,p_3 = F_a/S$$

Using eqs. (1) and (2) and the data given in Fig. 1, we obtain:—

$$150000 - 2 \times 0{\cdot}96 \times 90 \times \frac{1{\cdot}58 \times 10^{-2}}{39{\cdot}4 \times 10^{-4}} \times \frac{v^2}{s^2} = 795\,F_a$$

and

$$150000 - 0{\cdot}0695\,v^2/s^2 = 795\,F_a$$

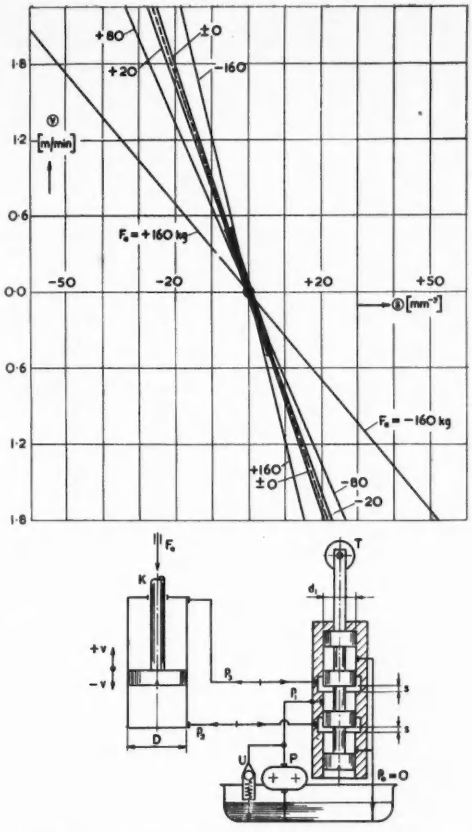

Fig. 1. **Flow control system : Circuit and characteristics.** p_1 = 15 atm, D = 40 mm, d_1 = 20 mm, T = feeler, U = relief valve, K = feed piston, P = pump.

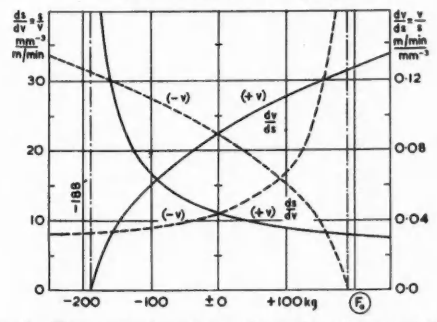

Fig. 3. **Flow control system : Operating characteristics.**

or finally $$\frac{v^2}{s^2} = 2161000 - 11450\,F_a \quad .. \quad (3)$$

The following conclusions can be drawn from the data in Figs. (1) and (3):—

(1) The system is very accurate, even with high feed rates.

(2) It is insensitive to force fluctuations (note that s is equal to the distortion between feeler and cutting tool, i.e., between the master and the workpiece).

(3) It is completely insensitive to force fluctuations and sudden force variations (e.g., reversal of frictional forces in the slideways, piston and piston rod, see Fig. 5.) at points of movement reversal (co-ordinate centres) or profile peaks. The work line is straight, showing no fluctuation at co-ordinate centres. Fig. 1 includes the work line for an idle stroke, in which the frictional resistance is taken to be equal to ± 10 kg; even during a working stroke no fluctuations are indicated on the line but only a slight bend at the zero point, as the cutting forces are steady and retain their sense (i.e., plus or minus).

(4) The system is particularly suited for force and velocity reversals and, therefore, for profile copying, using two equal and perpendicular systems, as it operates with complete symmetry in both directions, see Fig. 3.

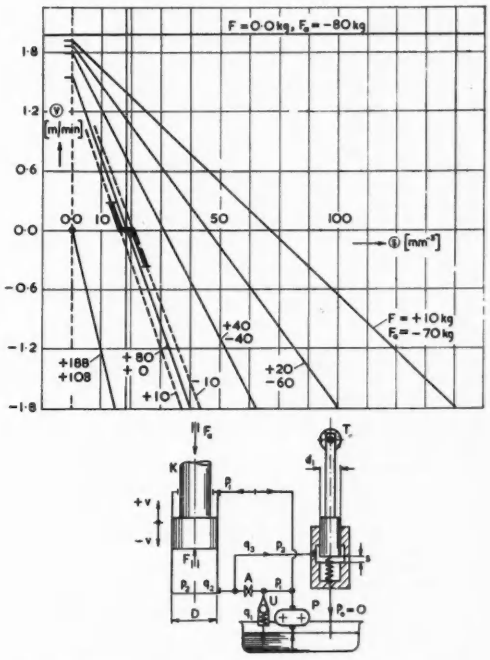

Fig. 2. **Pressure control system : Circuit and characteristics.** p_1 = 15 atm, A = 1 mm², D = 40 mm, d = 30·35 mm, d_1 = 20 mm, q = oil quantity, T = feeler, U = relief valve.

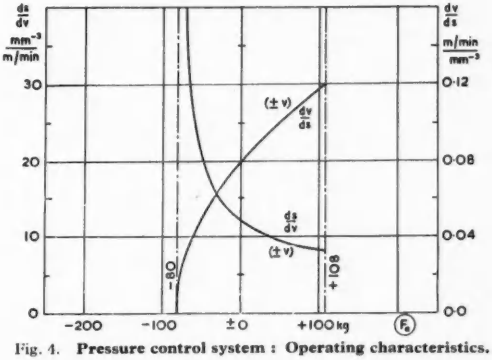

Fig. 4. **Pressure control system : Operating characteristics.**

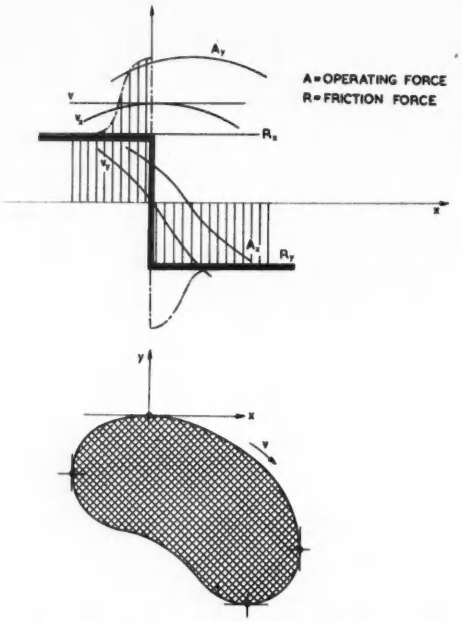

Fig. 5. **Diagram of working and friction forces in the main piston of a profile copying machine at profile peaks.**

In the pressure control system with a fixed opening A [mm²], illustrated in Fig. 2,

$$q_1 = q_2 + q_3 = Sv + q_3; \ (p_2 = F/S; \ F = \text{oil force})$$

$$p_1 - p_2 = 0{\cdot}96\,\rho\frac{q_1^2}{A^2} = \frac{0{\cdot}96\,\rho}{A^2}(Sv + q_3)^2$$

$$= \frac{0{\cdot}96\,\rho}{A^2}\left(S^2v^2 + 2\,S\,v\,U\,s\sqrt{\frac{p_2}{0{\cdot}96\,\rho}} + \frac{p_2\,U^2\,s^2}{0{\cdot}96\,\rho}\right)$$

$$= p_1 - F/S = \frac{0{\cdot}96\,\rho}{A^2}\left(S^2v^2 + 2\,S\,v\,U\,s\sqrt{\frac{F}{0{\cdot}96\,S\rho}}\right.$$

$$\left. + \frac{F\,U^2\,s^2}{0{\cdot}96\,S\rho}\right) = \frac{1}{A^2}\left(0{\cdot}96\,\rho\,S^2v^2 + 2\,S\,v\,U\,s\sqrt{\frac{0{\cdot}96\,\rho\,F}{S}}\right.$$

$$\left. + \frac{F\,U^2\,s^2}{S}\right)$$

and using data given in Fig. 2, we obtain

$$150 - 0{\cdot}795\,F = 136600\,v^2 + 41300000\,v\,s\sqrt{F} + 3130000000\,F\,s^2 \quad .. \quad .. \quad (4)$$

A large-section piston rod, with the entire pressure of $p_1 = 15$ atmospheres exerted on its side of the piston, is provided to obtain a system suitable for operation in both directions, and a new external piston force is obtained:

$$F_a = F - 80 \text{ (kg)} \quad \text{(see Fig. 2)}$$

The following conclusions can be drawn from the diagram in Fig. 2:

(1) The second system is almost as insensitive as the first at high feed rates.
(2) It is generally less resistant to force fluctuations, see Figs. 2 and 4.
(3) The system requires a certain distance, i.e., a true dead stroke, to achieve a new balance of forces at profile peaks, where the frictional resistance changes its sense intermittently, e.g., ± 10 kg for an idle stroke. This results in a straight-line inaccuracy at the peaks of machined profiles. The work line displays a double bend, with the dead stroke along the horizontal axis; the cutting forces displace the line horizontally to the left or right with a simultaneous change in the gradient of its inclined portion.
(4) Its operation at force or motion reversal points is very unsymmetrical and the system is therefore not really suitable for profile copying.
(5) The second system is not as capable of absorbing high forces as the first one, see Fig. 4, even if it is of similar size.

The force pressing the feeler against the master must be capable of overcoming the sliding resistance of the control valve in both the systems. A simple spring is therefore not suitable for profile copying, and other means, e.g., a magnetic attraction force between the feeler and the master, must be utilised. Such an arrangement also provides a constant profile feed rate due to the constant rotation of the circular feeler. The magnetic force should cause a tangential force sufficiently strong to displace the control valve, positioned at right angles.

The contact pressure can be very much smaller in a system with auxiliary or pilot control, and miniature magnetic feelers and masters of actual size can be employed. This avoids the need for mechanical transmission devices, such as pantographs, which reduce distortion s due to the feeler, but introduce more serious elastic or geometrical distortion or play.

From Fig. 6 it follows that:

$$p_2 = \beta\frac{q^2}{a^2} \quad (\beta = \text{discharge coefficient})$$

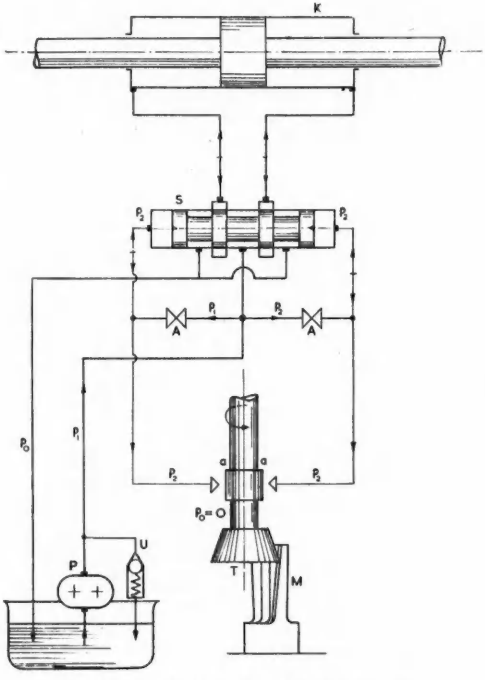

Fig. 6. **Circuit of a combined system.**
A = Fixed orifice, a = control port, U = relief valve, P = pump, M = master, T = feeler, K = feed piston, S = main control valve.

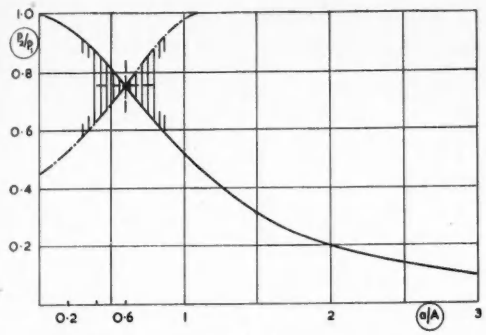

Fig. 7. **Pressure control p_2 by means of port a.**

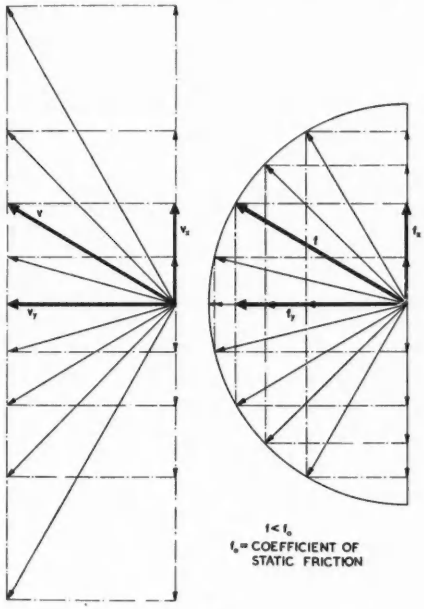

Fig. 8. **Velocity and friction diagram.**

and $$p_1 - p_2 = \beta \frac{q^2}{A^2} \quad \text{or} \quad p_1 - \beta \frac{q^2}{a^2} = \beta \frac{q^2}{A^2}$$

i.e., $$\frac{p_2}{p_1} = \frac{1/a^2}{1/A^2 + 1/a^2} = \frac{1}{1 + (a/A)^2} \quad \ldots \quad (3)$$

The effect on the main control valve S can be represented by dp_2/da or $\dfrac{d(p_2/p_1)}{d\,(a/A)}$ and it reaches a maximum value when the expression $\dfrac{d^2 p_2}{d\,[(a/A)]^2}$ equals zero:

The development is given below:

$$p_2 = \frac{p_1}{1 + (a/A)^2}$$

$$\frac{d\,p_2}{d\,(a/A)} = -2\,p_1 \frac{a\,A}{1 + 2\,(a/A)^2 + (a/A)^4}$$

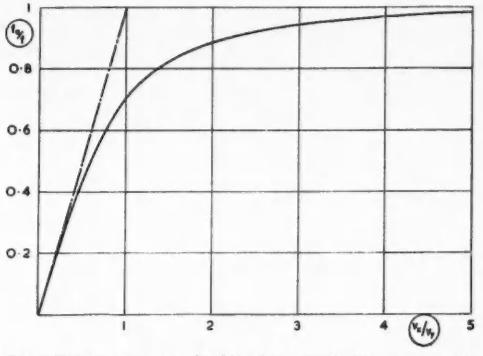

Fig. 9. **Friction diagram f_x with a lateral velocity component v_y**

$$\frac{d^2 p_2}{d\,[(a/A)]^2} = -2\,p_1 \frac{1 - 2\,(a/A)^2 - 3\,(a/A)^4}{[1 + 2\,(a\,A)^2 + (a/A)^4]^2} = 0$$

where $$a/A = 1\sqrt{3};\ (= 0{\cdot}577)$$

so that $$\left(\frac{d\,p_2}{d(a/A)}\right)_{\max} = -0{\cdot}649\,p_1$$

or $$\left(\frac{d\,p_2}{d\,a}\right)_{\max} = -0{\cdot}649\,p_1/A$$

and $$\left(\frac{p_2}{p_1}\right)_{\text{opt}} = 0{\cdot}75$$

When using two control ports a (for each co-ordinate direction) acting in opposition, both of which have an optimum value $a = 0{\cdot}577\,A$ when the feeler is central, twice the maximum effect on the main control valve S is achieved. The ports can, for example, be circular, having a diameter d, so that $a = 3{\cdot}1416\,d\,s$; with $A = 0{\cdot}7854$ mm^2 and $d = 5$ mm, $s = 0{\cdot}0288$ mm; and with $p_1 = 15$ atm and the face area of the control valve S being 2·35 cm^2, the effect on the control valve would be:

$$dP/ds = 918\ \text{kg/mm} = 0{\cdot}918\ \text{kg}/\mu$$

It is therefore clear that, under normal conditions, a deflection of only a few μ will be sufficient to displace the main control valve.

The distortion s is basically independent of the feed rate and force in this system and it is only influenced by the friction force of the control slide. Very small deviations from this law, i.e., a limited dependence of the distortion s on the feed rate and velocity, only occur under accelerated and abnormal conditions, as more fully described below.

The above mentioned reproduction accuracy and the exceptional stability at profile peaks can further be increased by reducing the friction force f_x for the displacement v_x of the control valve or by eliminating it altogether. This can be achieved by a lateral movement, in this case a rotation v_y of the valve; referring to Fig. 8, it follows that:

$$f_x = f \sin \tan^{-1} v_x/v_y = f\sqrt{1 + (v_y/v_x)^2}$$

(see Figs. 8 and 9, under the assumption of dry friction i.e., f = constant). It follows, therefore, that with small values of the ratio v_x/v_y, friction f_x will be proportional to that ratio, i.e., $f_x = f\ v_x/v_y$, and with

$$v_x = 0, \text{ it follows that } f_x = 0.$$

Moreover, the high value f_0, normally reached by f when starting, with dry friction or boundary lubrication, is always avoided with this system.

It is also preferable that both the main pistons should have a rotational movement so that the friction force R_y remains steady and passes through the zero point during movement reversal, see Fig. 10, contrary to the normal jerky course, Fig. 5. The cutting forces A have no effect at profile peaks or during movement reversal, since both their components are steady. The friction force components R_x, perpendicular to movement reversal, are similarly steady.

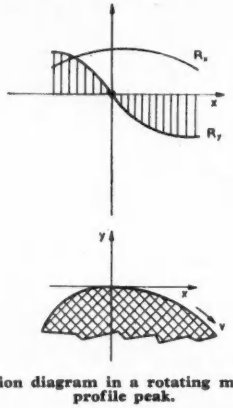

Fig. 10. **Friction diagram in a rotating main piston, at a profile peak.**

The friction in the slides can also be reduced by providing them with balls or rollers and so introducing rolling friction.

The instability of the forces, particularly during movement reversal, has thus been completely eliminated to prevent distortion. Distortion, however, is sometimes caused by the copying device itself, as in the system shown in Fig. 2, and can be due to the elasticity of the machine, the oil pipes and the oil, or due to the presence of air in the oil. Air can never be completely excluded from the oil, nor can a certain elasticity of the machine be avoided. It is therefore essential that the forces should be kept steady, and this can to a great extent be achieved by the measures described above.

Without these precautions and assuming dry friction, f = constant, the distortion would follow the path shown in Fig. 11 for an idle stroke. With boundary lubrication or dry friction, as shown in Fig. 12 for an idle stroke, the path would show oscillations. A similar phenomenon is noticeable with normal hydraulic machine tools with throttle control, mainly at extremely low table traverse rates used for wheel dressing on grinding machines. The distortion at profile peaks and the oscillations are strongly influenced by the set feed rate v_x, assuming dynamic stability.

Appendix

The system employing flow control is very sensitive to inaccuracies of the slide valve. Inadequate tolerances cause a deterioration of the working accuracy. A positive overlap, i.e., oversize on the width, is by far the most serious because its effect is fully reflected in instability at profile peaks. Dimensional distortion due to an inaccurate cylindrical fit can be kept small, because a satisfactory cylindrical fit can be achieved by using quite simple machining methods for the finishing of the valve periphery. Finally, a negative overlap, i.e., undersize on the width, increases dimensional distortion only when very small feed rates are used; with high feed rates, a negative overlap decreases dimensional distortion. The qualitative influence of a combined loose cylindrical fit and a negative or positive overlap on the width of the slide valve can be assessed from the above information.

The only relevant inaccuracy in the pressure control

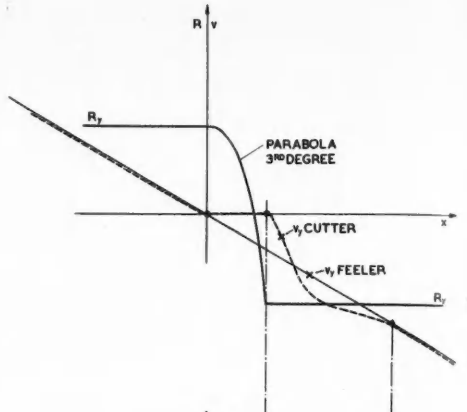

Fig. 11. **Velocity and distortion diagram with steady dry friction, allowing only for elasticity of oil.**

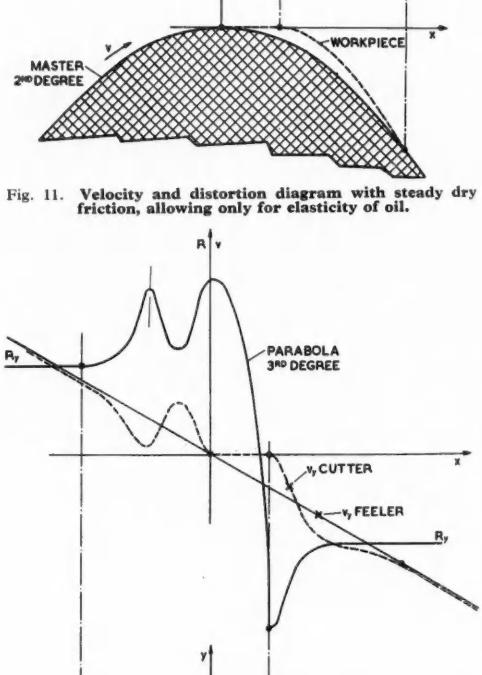

Fig. 12. **Velocity and distortion diagram with combined friction, allowing only for elasticity of oil.**

system, as shown in Fig. 2, is a loose cylindrical fit, and it has only a limited influence on distortion.

A system in which the relay is operated by air pressure, e.g., Monarch copying lathes, suffers from considerable lag due to the elasticity of air.

The Temperature Limit of Power Cables

By N. KLEIN, Institute of Technology, Haifa.

The increase of the working temperatures of cables is of great importance nowadays, as is shown by papers written on the subject, and especially the discussions which take place at the CIGRE conferences reveal that much work is being done in this direction. From these and from the great variations of the limiting temperatures in the specifications, confusion in the matter is discernible. This article is an attempt to clarify matters by describing the fundamental principles which have to be taken into consideration when determining the maximum working temperatures of cables.

1. INTRODUCTION

THE highest temperatures or temperature increases at which solid-type cables with oil-impregnated paper insulation are permitted to operate differ widely among the specifications of different countries. Kopeliowitch[1], in a comparative investigation, showed that while strand temperatures higher than 80° C are permissible in the U.S.A. or the U.S.S.R., some countries restrict these temperatures to about 50-60° C. These discrepancies are all the more remarkable when it is realized that the cable can be heated to 120° C before chemical deterioration sets in. Of course, the load-carrying capacity of a cable can be limited by the voltage drop, in which case the temperature increase is small. When this or a similar factor does not limit the magnitude of the current, it is the elevation of temperature which determines the maximum permissible current.

The temperature increase can cause changes not only in the chemical properties but also in the electrical and mechanical properties of the cable. The chemical changes occur in the first instance as decomposition of the paper. The electrical changes are principally manifested in the power factor and the conductivity of the oil. Further considerable changes occur in the electrical properties of the insulation during the process of cooling, when sparking takes place in the voids formed by this process. The mechanical changes are connected with the repeated heating and cooling of the cable, which, on repetition, can lead to fatigue cracks in the lead sheath.

These changes are mostly reversible in cables operating on normal load. When, however, the normal load and temperature are exceeded, the cable materials alter permanently. Such alterations accumulate in the course of repeated load cycles and may cause electrical or mechanical failure.

The following discussion will show how the cable properties change with varying temperature and how they determine the limits of cable loading. It will also show some possibilities of increasing these temperature limits.

2. THE TEMPERATURE STABILITY OF THE PAPER

When the temperature of the cable is increased, the paper of the insulation is the first to show signs of chemical deterioration. Clark[2] and Murphy[3] investigated the stability of paper in relation to temperature. They found that decomposition of the paper is already measurable below 100° C, but the rate of decomposition is negligibly small. 120° C is the temperature at which the decomposition becomes technically important. This temperature, therefore, constitutes an upper limit for paper-insulated cables.

3. THE ELECTRICAL PROPERTIES

The variation of the electrical properties with temperature depends mainly upon the oil, because the paper properties are fairly constant. Some electrical properties of the oil vary only slightly with temperature, such as the electrical breakdown strength, which usually has a low maximum between 60-80° C. Further, substantial electrochemical deterioration is not observed with the high-quality impregnating oils which are used, e.g., in pressure cables up to 85° C.

On the other hand, variations of the power factor and conductivity have to be carefully considered. The conductivity of lower-voltage cable oils and the power factor begin to rise at a rapid rate at 50° C, and the magnitude of the dielectric losses which is $2\pi f V^2 C \tan \varphi$ (f being the frequency, V the voltage, C the capacitance and $\tan \varphi$ the power factor) can be calculated. Assuming that the cable has a very bad power factor of 0·1 at temperatures above 100° C, the dielectric losses become considerable above 10 kV. Such dielectric losses cause an increase in the running costs and additional heating of the cable, and the current-carrying capacity of the cable is decreased. In severe cases, thermal instability is the consequence. To prevent the power factor deterioration with temperature, better quality oils and better impregnation are used for higher-voltage cables. Whitehead[4] and others described in detail the various factors determining the magnitude and variation of the power factor. By the use of pure, well dried paper, pure oil, and under conditions of great cleanliness in manufacture, high-voltage pressure cables are made with power factors of the order of 0·003-0·004, which increase very little at the maximum copper temperatures of 85° C.

Such a temperature is not reached at present by ordinary solid-type cables for voltages between 10 and 33 kV for reasons discussed in the following paragraphs and as the variation of the power factor is unimportant for cables below 10 kV, the oil properties are generally not the determining factor for the temperature limit of the cables. The strand temperature of pressure cables, however, could even exceed 85° C by using good-quality impregnating oils.

4. VOID FORMATION ON COOLING

Void formation becomes dangerous where sparking occurs; low-voltage cables are, therefore, not limited by this process. Voids form more readily the higher the temperature drop during cooling, the higher the oil viscosity and the thicker the insulation. As the thickness increases with voltage, high-voltage cables are unfavourable from this point of view. This is recognized in standard specifications by temperature limits which are 15-20° C smaller for 20-kV cables than for lower-voltage cables.

On heating, the expanding oil, which has an expansion coefficient four times that of the paper, flows through the insulation to the sheath (when the conductor is circular), and returns during the cooling process in a reverse manner. Permanent compression of the paper insulation and extension of the lead sheath is a consequence of these processes. The return flow of the oil from the sheath into the insulation and the conductor is governed by the rate of cooling. To avoid the formation of voids, the contraction of the oil should be smaller than the quantity of oil which can flow back into the paper insulation due to the capillary forces and the forces of pressure under the lead sheath.

It is possible to calculate approximately the pressure p which is necessary for the return flow of the oil (for details see Appendix).

$$p = C \theta_0 \eta e^{-kt}$$

This pressure is proportional to a constant C of the cable (value given in the Appendix), to the temperature drop of the cooling process θ_0, to the average oil viscosity η and to e^{-kt}, where k is a constant giving the rate of cooling and t the time. Taking as an example a 33-kV, 0·25 sq. in. single-core cable, the pressure p was calculated as a function of time and plotted in Fig. 1. As can be seen, the pressure at the begining of the cooling process is small in spite of the fact that the largest quantity of oil flows back into the insulation, because the viscosity of the warm oil is small. The pressure becomes a maximum 6-7 hours after cooling begins, when the viscosity is already high. The maximum pressure in this case is 0·11 kg/cm² (1·6 psi), the average temperature drop of the insulation being 50° C and that of the strand 60° C. Experiments were made by Domenach[5] to determine pressure drops due to oil flow through the insulation in oil pressure cables, and the order of magnitude of the pressures found by him correspond well with the values calculated from the above equation.

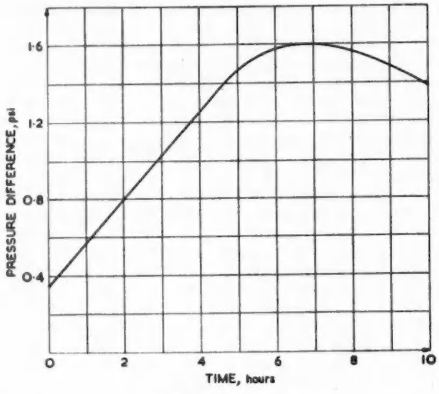

Fig. 1

The pressure required for the oil flow to replace the contraction is thus considerable. The capillary forces help to draw the oil into the paper. They set up a pressure difference p_c, the magnitude of which can be roughly estimated from the well-known relation for pressure differences across spherical liquid surfaces, as $p_c = 2\nu/r$, ν being the surface tension and r the average radius of the pores in the paper. The surface tension of oil is 36 dyne/cm² and $r = 0{\cdot}001$ cm, thus $p_c = 72000$ dyne/cm², or approx. 0·1 psi. In this case, the capillary forces would probably be insufficient to draw in enough oil and sparking would occur. In cases where only capillary forces are present, it is expected that the contracting oil of the paper will draw oil from gaps between the paper tape and enlarge voids already existing there.

Insufficient return of oil can be well observed with cables which for some reason were not sufficiently impregnated and have voids in the insulation. Thus, a 33-kV, 0·75 sq. in. single-core cable which had a power factor of 0·01 at room temperature and working voltage, was heated to a strand temperature of 105° C. The power factor 16 hours later, when the cable was again at room temperature, was 0·013 and returned to 0·01 only after a further 24 hours.

The quantity of oil flowing back is sufficient when a corresponding pressure acts on it under the lead sheath. This usually happens when the lead sheath is loosely extruded on the insulation. Air is then included under the sheath. It partly dissolves in the oil, and partly forms bubbles. The pressure in these bubbles should be of the order of 5 psi in cold cables and much higher when the cable is warm. It is thought that the pressure in these bubbles considerably assists the return of the oil on cooling, especially with well impregnated cables, where there are no voids in the insulation.

The pressure in such bubbles and their existence depend on the method of sheath extrusion and are, therefore, an uncertain factor. In reality the 0·25 sq. in. 33-kV cable of the first example would not be loaded to cause a temperature increase of the strand by 60 °C, but only by about 35-40° C, in which case the maximum of the pressure due to oil flow would be only about 0·9 to 1 psi. In such a case the capillary forces just prevent void formation. The uncertainties regarding the magnitude of the forces preventing voids partly explain the discrepancies in the temperature specifications of various countries.

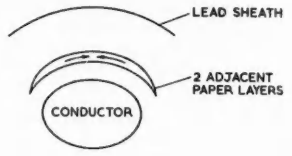

Fig. 2

The problem connected with the return of the oil on cooling led to the introduction of oval cables for higher voltages. In these cables, the expanding and contracting oil, on the whole, does not flow through the paper. On expansion, the cable becomes more circular, thus increasing its cross-section. The oil flows between adjacent paper layers as shown by the arrows in Fig. 2, and finds space in the enlarged gap of the paper layers. On cooling, the cable insulation receives its oval shape again due to capillary forces, and sufficient oil flows in the opposite direction, preventing void formation. Comparing the cross-section of an ellipse and a circle, it can easily be shown that the minor-major axis ratio of such cables should be about 0·86, if oil flow through the paper is to be avoided on cooling by 45° C.

Oval cables make possible an increase of the temperature limits of high-voltage cables, especially when covered with loose sheathing.

5. FATIGUE CRACKS IN THE LEAD SHEATH

One of the most important factors limiting the temperature of cables is the fatigue strength of the lead sheath. The temperature differences due to the daily load changes cause, amongst other things, elongation and shortening of the cable. Where the effects of the length changes concentrate, as, e.g., in joint manholes, fatigue cracks can develop.

The thermal expansion of the cable is not easy to evaluate, partly because the thermal expansion coefficients of the composing materials differ considerably (the linear thermal expansion coefficient of copper is $16{\cdot}2 \times 10^{-6}$ in./in./°C, and of lead $29{\cdot}1 \times 10^{-6}$ in./in./°C, and the cubical thermal expansion coefficient of paper 170×10^{-6} cu.in./cu.in./°C, and of oil 700×10^{-6} cu.in./cu.in./°C), partly due to the plastic properties of those materials and partly due to the method of laying the cable. The cable expansion on heating causes deformations, such as snaking, or bending in the joint manholes. The deformations usually occur in such a way that the strain energy is at a minimum.

When the cable is prevented from elongating, or moving sideways, as when laid directly in strongly compacted earth, the thermal expansions are radial. The copper wires of the strand lengthen by increasing their winding diameter and by pressing into the paper insulation. This effect can be seen very well when a used cable is opened up and deep grooves are found in the inner layers of the insulation. The volumetric expansions of copper, paper, and oil cause a radial expansion of the lead sheath, usually in the form of

permanent deformations. The lead sheath cannot elongate, and therefore either wrinkles or, if sufficiently thick, becomes compressed plastically by an amount equal to that by which it should elongate thermally. For example, when, as is often the case, the daily temperature rises of the cable sheath are 25° C, the sheath length should increase by $25 \times 29{\cdot}1 \times 10^{-6} = 7{\cdot}3 \times 10^{-4}$ in./in., and as the length cannot change, a pressure is created in the lead corresponding to a strain of 0·073 per cent. This strain is far above the yield stress of lead, and the lead deforms plastically.

When, however, the cable is free to move, as is sometimes the case in ducts, and very often in joint manholes, where the joint is offset, as shown in Fig. 3, the thermal elongation is not transformed plastically into radial expansion. The elongation in the manhole and in the end parts of the ducts causes considerable bending, as shown by the dotted lines, and large strains in the lead sheath. When these strains are of the order of several tenths of a per cent, their cumulative effect in the course of time causes fatigue cracks in the sheath.

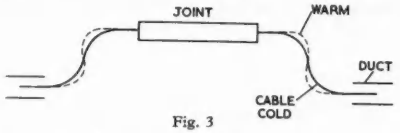

Fig. 3

A considerable number of observations and investigations was carried out on the occurrence and causes of fatigue cracks, and recent results[6, 7, 8, 9] permit certain conclusions. When lead is repeatedly bent, fracture of the metal occurs after a certain number of bending cycles. The number of these cycles decreases rapidly with increasing strain and increasing temperature, as was shown by Dollins (the nature of this is shown by curves in Fig. 4). This explained the fact that repeated strains of 0·2 per cent could already cause fatigue cracks in pure lead cable sheaths. Thus, a limit was set to the permissible temperature variations of cables in the specifications. The position improved with the recent introduction of certain alloyed lead sheaths[10, 11] and especially of arsenical lead alloy sheath. This alloy has a much higher fatigue strength than pure lead, because the permissible strain is doubled for the same number of cycles to failure. In consequence, an increase in the daily temperature variations in such cables by about 50 per cent should be permissible.

Fundamental for the prevention of fatigue cracks is the laying of cables in such a manner as to minimize thermal movements, snaking and bending or, if possible, complete immobilization. Daily temperature differences of the sheath of, e.g., 50° C, would cause strains of a magnitude of 0·15 per cent in the immobilized section owing to the prevention of thermal expansion. If the results of fatigue tests due to repeated bending can be applied to this case of repeated compression, no fatigue cracking is to be feared. Such high sheath temperature differences, however, correspond to conductor temperatures which are much above those permitted by present-day standards.

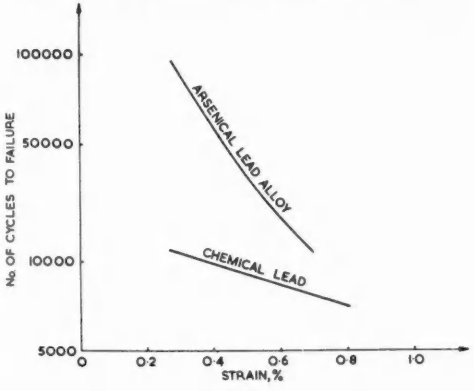

Fig. 4

The temperature limit of high-voltage pressure cables depends also on the fatigue properties of the lead. The nature of deformation, however, varies considerably according to the type of pressure cable and cannot be described briefly. The treatment of their fatigue properties and the consequent temperature limits is therefore omitted here.

6. CONCLUSION

The temperature limits of cables are determined mainly by the fatigue strength of the lead sheath and the conditions of void formation on cooling. The influence of both factors depends mainly on the number of load cycles and on the magnitude of the temperature variations of the cable. When there are very small temperature variations or none at all, these factors do not limit the maximum cable temperature. In usual practice, however, large daily temperature variations occur and the temperature limits are determined as follows:

The limiting factor for cables below 10 kV is only the fatigue strength of the sheath, and conductor temperatures up to 85° C are permitted by specifications. Recent advances in better alloys for the sheath might permit higher temperatures. A similar advantage might be gained by careful laying of cables, and by preventing or minimizing thermal movements; this, of course, increases costs.

The temperature limits of medium and higher-voltage cables are determined mainly by the need to prevent or restrict void formation on cooling. Thus, the limits decrease with voltage and, e.g., the maximum temperature of 33-kV cables is about 55° C. The cables are preferably oval at higher voltages to improve oil flow.

Sparking through void formation is completely prevented in high-voltage pressure cables; therefore, their working copper temperatures are elevated again in some cases up to 85° C. The magnitude of the power losses in the dielectric plays a very important rôle at the highest voltages; expensive impregnating oils of special quality are used, and the power factor of the insulation is maintained at all temperatures at approximately 0·004. The influence of the temperature on the mechanical properties varies considerably according to the type of the pressure cable. The limiting factor of the temperature of pressure cables is generally due to the mechanical properties of the sheath, and the introduction of arsenical or other lead alloys is an improvement.

8. APPENDIX

The pressure drop p which occurs across the insulation, when the oil is flowing from the cable sheath into the insulation through the paper to replace the contracting oil, can be calculated approximately in this way:

It is assumed that the weighted average temperature of the insulation is θ_0 at the beginning of the cooling and that this temperature θ decreases with time t as

$$\theta = \theta_0 e^{-kt} \quad .. \quad .. \quad (1)$$

k being a constant.

The volume decrease of the insulating oil, dv, on cooling per unit length of cable is

$$dv = [\pi \beta (r_o^2 - r_i^2) + v_r] \alpha_{oil} d\theta \quad .. \quad (2)$$

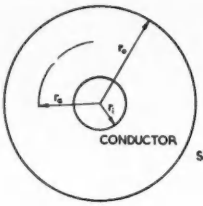

Fig. 5

β being the fraction of oil in the insulation, r_o the outer and r_i the inner radii of the insulation, v_c the oil volume per unit length of strand and α_{oil} the cubic thermal expansion coefficient of the oil.

As the paper also contracts radially on cooling, the quantity of oil flowing through the paper, dv^*, is smaller than the total oil volume decrease, and α_{oil} in eq. (2) is replaced by

$$\alpha = \alpha_{oil} - \alpha_{paper} \quad .. \quad .. \quad (3)$$

Accordingly $dv^* = [\pi \beta (r_o^2 - r_i^2) + v_c] \alpha \, d\theta$ (3a)

The quantity dv^* flows through the first layer of thickness dr of the paper owing to a temperature drop $d\theta$ in time dt. The oil quantity flowing through subsequent layers decreases towards the conductor. The quantity flowing through paper at the conductor corresponds to the oil concentration in the conductor.

To simplify calculations, it is assumed that the pressure drop from the sheath to the conductor is the same as if the whole quantity of oil dv^* were flowing from the sheath to an average radius r_a.

The pressure drop dp, when oil flows through a paper layer of thickness dr is, according to Darcy's law for liquid flow through porous materials,

$$dp = -\eta \chi u \, dr \quad .. \quad .. \quad (4)$$

where η is the oil viscosity, χ the flow resistivity of the paper and u the flow velocity.

The flow velocity

$$u = -\frac{dv^*}{dt}\frac{1}{2\pi r} \quad .. \quad .. \quad (5)$$

where $2\pi r$ is the area for unit length of cable through which the oil flows.

Replacing the expression for dv^* from eq. (1) and (3a) and putting $[\pi \beta (r_o^2 - r_i^2) + v_c] = v_o$

$$u = \frac{\alpha v_o k \theta_0 e^{-kt}}{2\pi r} \quad .. \quad .. \quad (5a)$$

and with eq. (4)

$$\frac{dp}{dr} = -\frac{\eta \chi \alpha v_o k \theta_0 e^{-kt}}{2\pi r}$$

Integrating between the limits r_a and r_o, the pressure drop in the insulation due to oil flow becomes

$$p = \frac{\chi \alpha k v_o \log (r_o/r_a)}{2\pi} \theta_0 \eta e^{-kt} \quad .. \quad (6)$$

The fraction is constant and characteristic for the cable; designating it by C

$$p = C \theta_0 \eta e^{-kt} \quad .. \quad .. \quad (6a)$$

In this expression, e^{-kt} is decreasing with time; on the other hand, the viscosity increases as the cooling progresses. In consequence, p reaches a maximum value as is shown in Fig. 1, representing the cooling process of a 33-kV, 0·25 sq. in. single-core cable, where the pressure is plotted against time. The individual values replaced in eq. (6) are in c.g.s. units $\chi = 2{\cdot}5 \times 10^{10}$ (according to measurements of the flow resistivity of paper perpendicularly to its surface by the author and A. M. Morgan).

$\alpha = (700 - 170) \times 10^{-6} = 530 \times 10^{-6}$,
$k = 64 \times 10^{-6}$ (assuming 10 hours for 90 per cent of the cooling to be completed)
$v_o = 3{\cdot}95$, $r_a = 1{\cdot}7$, $r_o = 1{\cdot}27$, $\theta_0 = 50°$ C.

The viscosity η is 209 poises at 15° C and decreases in approximately exponential manner.

This calculation shows only the principles of approach for the estimation of the pressure drop p. A more detailed calculation, which takes into account the decrease of the oil flow quantity towards the conductor and the variation of the viscosity across the insulation, leads to formulae similar to eq. (6). A rigorous expression for p, however, is not available, because the exact temperature distribution during cooling is not known.

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The Effect of Ferromagnetic Material on the External Circuit of a Resistance Welder

By A. S. GELBMAN and E. S. SLEPYAK. (From *Avtogennoye Delo, Russia*, Vol. 22, No. 2, February, 1951, pp. 4-6, 7 illustrations.)

THEORETICAL analysis and experimental investigation show that the introduction of a ferromagnetic material (i.e., the work) between the electrodes of a resistance welding machine affects the resistance of the external (welding) circuit as follows. The overall resistance in the circuit increases as the result of an increase in both the active and the inductive components, the former often being important; the effect of the ferromagnetic material introduced is determined neither by its mass nor its cross-sectional area, but solely by its configuration; constant output of the welding circuit can be assured by increasing the secondary transformer voltage; increasing the electrode gap decreases the sensitivity of the circuit to the introduction of external ferromagnetic material.

In spot and seam welding, the introduction of the work considerably modifies the resistance of the external or welding circuit and subsequently affects the intensity of the welding current. The problem of the effect of introduced ferromagnetic material on the behaviour of the welding circuit thus calls for further investigation. Contrary to the opinion held hitherto, both theoretical analysis and practical experiments have shown that both the inductive and the active components of the circuit resistance are affected, and that in certain cases the active component can be of predominating importance. In the simplest welding circuit, consisting of a rectangular frame composed of circular-section conductors, the area of which depends on the depth of throat and gap between the jaws, since the directions of the current in parallel conductors are opposed, the coefficient of mutual induction will be negative. The inductive resistance of the circuit is thus decreased by the amount of mutual inductance of the parallel conductors and proportionally to the variation of the electrode gap; in the simplest case, namely, the introduction of a flat steel sheet of infinite permeability, the inductivity of the circuit will be determined by mirroring an equivalent current on the plane of the body introduced, the currents thus being equal in magnitude and direction. Analysing the corresponding conditions for parallel conductors with a ferromagnetic body of infinite permeability

(*Concluded on page* 414)

The Bifilar Pendulum for the Damping of Torsional Vibrations

By L. DEVAUX. (From *Revue Universelle des Mines*, 9th Series, Vol. 7, No. 8, August, 1951, pp. 237-250
20 illustrations.)

This article describes the advantages of the Sarazin type of bifilar pendulum damper for the suppression of harmonics of various orders in engine systems.

IN the case of generator sets running at a constant speed, it is always possible to develop the system in such a way that there will be no resonance effects at the running speed. However, in general the engine is required to operate over a wide range of speeds and it is not possible then to eliminate the resonance effects completely. A vibration damper is therefore required, in order to be able to operate the engine at a critical speed without danger to the shafting.

The Lanchester damper consisting of two friction members in the form of discs pressed together by a spring force which is adjustable in order to obtain optimum friction has been extensively used. It dissipates the vibratory energy in the form of friction. Another type is the Frahm damper, which consists of two masses coupled together by springs. This arrangement constitutes a tuned system which has its own natural frequency. If this is equal to the excitation frequency of the crankshaft, the damper reaction becomes equal to the shaft torque, which is thus cancelled out. This is, therefore, an ideal arrangement for vibration elimination; but, unfortunately, it is only effective for the one frequency to which the Frahm damper is tuned.

The exciting torque in an internal combustion engine has a frequency which is proportional to the engine speed. It is thus an advantage to have a seismic element which will vibrate with a frequency varying with the engine speed. This can be achieved by means of the arrangement shown in Fig. 1, in which the effect of the springs is replaced by that due to centrifugal force. The pendulum C is capable of oscillating about its pivot at D, but tends to come back to its mean position under the effect of the centrifugal force, which is proportional to the square of the engine speed. Thus, the vibration of A will act as an exciting force on C which will react on A so as to suppress the shaft vibration at A.

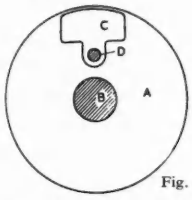

Fig. 1

For reasons which will be explained later, the simple pendulum arrangement of Fig. 1 is not used but is replaced by one of the following designs:—

1. The bifilar-suspension damper (Fig. 2), which has a comparatively large seismic mass, oscillating on two rollers, with a very small amplitude of vibration. This type is used particularly on Curtis-Wright engines.
2. The pendulum damper, in which the pendulum consists of a cylinder with its centre at B (Fig. 3), sliding in a cylindrical cavity of somewhat larger diameter which has its centre at A. As the mass of the cylinder is much smaller than that of the bifilar pendulum, its vibration amplitude will be correspondingly greater. This system is applied in Pratt & Whitney engines.

It can be said that all problems of flexural or torsional vibration are reducible to differential equations of a similar type, which include inertia forces, shaft stiffnesses and a damping force generally proportional to the vibration velocity. As the disturbing force is a harmonic of a given order of the engine torque, all the quantities considered are of the sinusoidal type, and the problem is analogous to that solved by vector

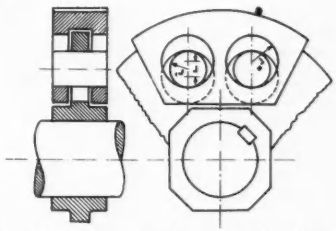
Fig. 2

methods in electricity for a circuit consisting of resistances, capacitances and inductances.

In the following lines, an analysis will be given of a simple oscillating system. This will be followed by a study of the vibration of a main system coupled to a freely vibrating "dynamic absorber" system introduced in order to limit the vibration amplitude. The

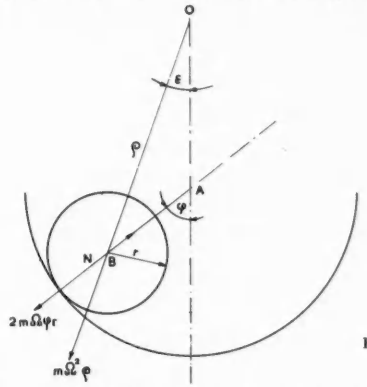

Fig. 3

analysis will cover the cases in which the absorber system has a constant natural frequency and where its frequency is proportional to the exciting frequency. The behaviour of the absorber will be investigated in detail and the formulae required for its design will also be given.

1. SYSTEM WITH ONE DEGREE OF FREEDOM

For a system such as that shown in Fig. 4, consisting of a mass with a moment of inertia I [kg cm sec²] at one end of a shaft of stiffness k [kg cm/rad], which is clamped at its other end, under the action of a vibratory torque $T_s \sin \omega t$ and a damping torque $c\dot{\varphi}$ (not indicated in the figure), the amplitude of vibration φ at any instant is determined by the equation of motion:—

$$\ddot{\varphi} + 2\gamma\omega_1\dot{\varphi} + \omega_1^2\varphi = (T_s/I)\sin\omega t \qquad (1)$$

where $\gamma = c/[2\sqrt{kI}]$ = relative damping, and $\omega_1 =$

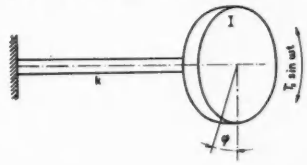

Fig. 4

$\sqrt{k/I}$ = radian frequency of the undamped system. The system will have a periodic vibration if $0 < \gamma < 1$, and this case only will now be considered. The steady-state solution of eq. (1) is of the form

$$\varphi = \Phi_1 \sin(\omega t - \epsilon) \quad .. \quad .. \quad (2)$$

where ϵ = phase angle. The substitution of this expression for φ in eq. (1), using also the following ratios

$\omega/\omega_1 = F$ = ratio of exciting frequency to natural frequency of undamped system,

$T_s/k = T_s/(I\,\omega_1^2) = \Phi_s$ = static (or equilibrium) amplitude due to torque T_s applied at zero frequency,

$\Phi_1/\Phi_s = M$ = dynamic magnification of amplitude,

$\Phi_{1r}/\Phi_s = M_r$ = dynamic magnifier at resonance,

enables eq. (1) to be re-written as follows:—

$$-F^2 \sin(\omega t - \epsilon) + 2\gamma F \sin[(\pi/2) + \omega t - \epsilon] + \sin(\omega t - \epsilon) = (1/M) \sin \omega t \quad .. \quad (3)$$

The problem is therefore solved by means of Fig. 5 and the following expressions:—

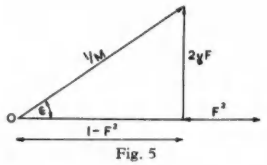

Fig. 5

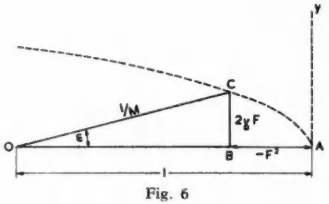

Fig. 6

$$1/M = \sqrt{4\gamma^2 F^2 + (1 - F^2)^2}$$

$$\Phi_1 = T_s/[\omega\sqrt{c^2 + [(k/\omega) - I\,\omega]^2}]$$

and $\tan \epsilon = 2\gamma F/(1 - F^2) = c/[(k/\omega) - I\,\omega]$.

The dynamic magnifier is

$$M = 1/\sqrt{4\gamma^2 F^2 + (1 - F^2)^2}.$$

Conditions at resonance:

$$F = \omega/\omega_1 = 1;\ M = M_r = 1/(2\gamma) = \sqrt{kI}/c;$$

$\tan \epsilon = \infty$, or $\epsilon = 90°$.

Conditions off resonance:

When the frequency ratio $F = \omega/\omega_1$ varies from zero to infinity, the tip C of the vector OC describes a parabola, as shown in the diagram of Fig. 6, which has the equation

$$y^2 = 4\gamma^2 x \quad .. \quad .. \quad .. \quad (4)$$

relative to the axes AO and AY of the figure. For a given value of the relative damping γ, the phase angle between the disturbance OC and the amplitude OA is greater when the damping $BC = 2\gamma F$ is increased.

From the general equation (3), we can derive the locus curve of the system, that is, the curve of the dynamic magnifier M as a function of the frequency ratio F:

$$1/M^2 = 4\gamma^2 F^2 + (1 - F^2)^2 \quad .. \quad .. \quad (5)$$

A locus curve of this type is shown in Fig. 7 for a value $\gamma = 0{\cdot}15$ for the relative damping.

The physical significance of the various vectors is as follows:—OA is proportional to the shaft reaction, that is, to the vibration amplitude; AB is proportional to the inertia torque of the vibrating mass; BC is proportional to the damping torque; and OC is proportional to the exciting torque. The locus curve can also be used to obtain the plot of the dynamic magnifier against frequency, as shown in Fig. 8. The maximum amplitude is reached at a value slightly below that of the resonant frequency $F = 1$ for the undamped system.

Furthermore, the amplitude of vibration becomes lower than the static amplitude for values of F greater

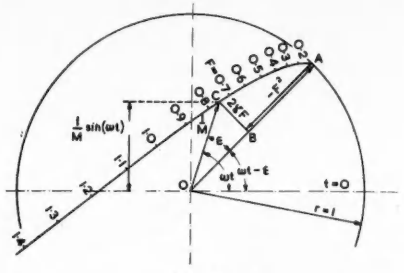

Fig. 7

than 1·4, i.e., 40 per cent higher than the natural frequency. At resonance, the amplitudes reach high values. To eliminate these from the operating range, there are various possibilities:—

1. Elimination of the disturbing torque: This is not practicable in reciprocating engines.
2. Shifting of critical speed out of the speed range. If the shift is to a lower speed, high transient stresses may be inevitable when starting or stopping. If the shift is to a higher speed, this requires the use of smaller engine inertias, or higher shaft stiffnesses, which is not easy and frequently impossible.
3. Reduction of vibration by increasing the natural damping. This dissipates energy by friction and therefore reduces engine efficiency.
4. Reduction of vibration by means of a dynamic absorber: This absorber produces a reaction which counteracts the vibration of the system.

SYSTEM WITH 2 DEGREES OF FREEDOM, INCLUDING ABSORBER TUNED TO CONSTANT FREQUENCY

The main system considered in the previous section will now be completed by the addition of a second system, generally rotating about the same shaft axis as the primary and acted upon by the main system through a spring arrangement.

The additional system is characterised by a moment of inertia I_2 and a spring stiffness k_2. The Frahm pendulum is of this type. To simplify the calculation, the damping of the pendulum is generally assumed to be zero. However, the resonance region is of particular interest to us, and in this region, the damping, however small, is a most important factor. Therefore, it will

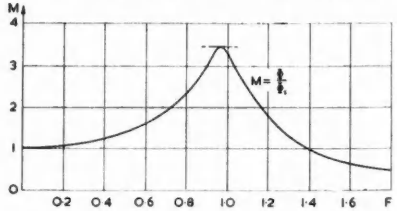

Fig. 8

also be taken into account in the following calculations.

The symbols used will be the same as previously, but the subscripts 1 and 2 will be introduced to denote the main system and the absorber, respectively.

The equations of motion of the complete system are:—

$$I_1 \ddot{\varphi}_1 + c_1 \dot{\varphi}_1 + k_1 \varphi_1 + k_2(\varphi_1 - \varphi_2) = T_s \sin \omega t$$

$$I_2 \ddot{\varphi}_2 + c_2 \dot{\varphi}_2 + k_2(\varphi_2 - \varphi_1) = 0 \quad .. \quad .. \quad (6)$$

Furthermore, let: $M_1 = \Phi_1/\Phi_s = \Phi_1/[T_s/I_1\ \omega_1^2]$ = dynamic magnifier of the main system, $\kappa = \mu(\omega_2/\omega_1)^2 = k_2/k_1$ = coupling ratio, and $\mu = I_2/I_1$. By substituting these ratios, as well as the parameters $\gamma_{1,2}$ and $F_{1,2}$ in eqs. (6), we obtain

$$-F_1^2 \sin(\omega t - \epsilon_1) + 2\gamma_1 F_1 \sin[(\pi/2) + \omega t - \epsilon_1)] + \sin(\omega t - \epsilon_1) - \kappa[(\Phi_2/\Phi_1)\sin(\omega t - \epsilon_2) - \sin(\omega t - \epsilon_1)] = (1/M_1)\sin\omega t \quad (7a)$$

$$-F_2^2 \sin(\omega t - \epsilon_2) + 2\gamma_2 F_2 \sin[(\pi/2) + \omega t - \epsilon_2)] + \sin(\omega t - \epsilon_2) = (\Phi_1/\Phi_s)\sin(\omega t - \epsilon_1) \quad (7b)$$

These equations can be represented graphically in the same way as when dealing with electrical problems. The result obtained is the polar diagram of Fig. 9, plotted for $\gamma_1 = 0{\cdot}15$, $\gamma_2 = 0{\cdot}10$, $\omega_2/\omega_1 = 1{\cdot}112$, $\mu = 0{\cdot}202$, and $\kappa = 0{\cdot}25$.

Eq. (7b) is expressed geometrically by the polygon $OA_2B_2C_2O$, and eq. (7a) by the polygon $OA_1B_1C_1D_1E_1O$). The diagram also includes the case in which no dynamic absorber is used. The comparison of the two systems is obtained by comparing the two vectors OC and OE.

It is found that OE_{min} is always greater than OC_{min}. Therefore, the dynamic magnifier M_1 of the main system reaches a lower value than the maximum of the system without a dynamic absorber. The effect of the absorber is expressed by the terms

$$-\kappa(\Phi_2/\Phi_1)\sin(\omega t - \epsilon_2) + \kappa\sin(\omega t - \epsilon_1)$$

in eq. (7a), that is, by the resultant C_1E_1 of the two vectors C_1D_1 and D_1E_1, which is, in effect, the torque transmitted to the absorber I_2 by the spring k_2.

The behaviour of the system will now be considered

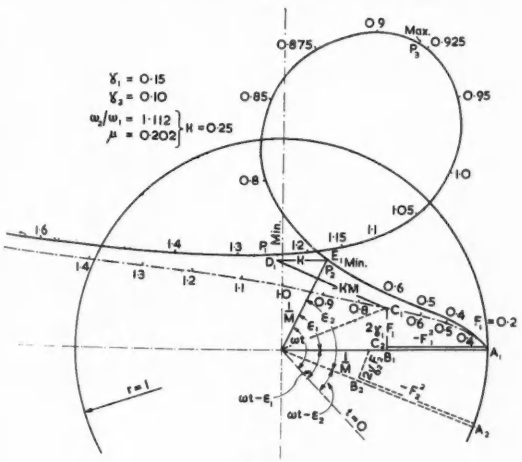

Fig. 9

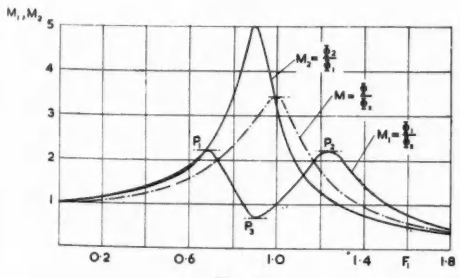

Fig. 10

by means of the polar diagram (Fig. 9) and the dynamic magnifier curves M_1 and M_2 (Fig. 10).

Polar diagram: The locus curve of Fig. 9 obtained by varying F_1 from zero to infinity is no longer a parabola. The tip of the vector OE describes a more complicated curve, which has two points P_1 and P_2 at a minimum distance from the origin. At these points, the dynamic magnifier has a maximum value. An intermediate point P_3 is at a maximum radius, corresponding to a minimum magnifier value.

Dynamic magnifier curves: The curve $M = \Phi/\Phi_s$ of the system without the absorber is shown as a chain-dotted line with a single peak at $F = 1{\cdot}0$. The curve $M_1 = \Phi_1/\Phi_s$ has two maxima P_1 and P_2, which are, however, lower than the original maximum. The point P_3 between the two peaks is the minimum amplitude corresponding to the point P_3 on the polar diagram. If the curve of $M_2 = \Phi_2/\Phi_1$ is also plotted on the same base, it is seen that its maximum is over point P_3; that is, the absorber is then in resonance with the exciting torque.

Optimum conditions: To obtain a minimum value of M_1, the vector OE_1 should be as small as possible. If the main system cannot be altered, the changes can only be made on the absorber side. This means that the vector C_1D_1 must be increased, or that a value as large as possible must be obtained for Φ_2/Φ_1, corresponding to a minimum for vector OC_2 which is proportional to Φ_1/Φ_2. This is obtained when $F_2 = 1$ by making the natural damping of the absorber as small as possible.

This result may seem surprising, but it should be remembered that the pendulum acts by means of its inertia and, therefore, its action should not be damped.

An increase in OE_1 could be obtained by increasing the coupling factor $\kappa = (\omega_2/\omega_1)^2(I_2/I_1)$, but this would mean increasing the inertia of I_2, which would result in a larger and heavier absorber. In practice, the solution is found in the opposite direction: a small coupling factor is accepted, but as the moment of inertia is small, the amplitude I_2 is allowed to increase, so as to obtain a large Φ_2/Φ_1 ratio for optimum working conditions.

The disadvantages of the dynamic absorber tuned to a constant natural frequency are as follows:—

1. The absorber gives rise to two resonance peaks instead of one; although these are of lower amplitude, they may still be troublesome.
2. It is only efficient if its own natural frequency coincides closely enough with the exciting frequency. As soon as the exciting frequency varies, the effect of the absorber is negligible. Best use of this absorber is therefore obtained on synchronous machines.

In internal combustion engines, the frequency of the torsional vibrations varies with the engine speed which determines the forcing frequency. The Frahm pendulum is not effective under such conditions. Instead of using a restoring force produced by a mechanical spring with a stiffness k, it is then an advantage to make use of centrifugal force, which acts as a spring with a stiffness proportional to ω^2, and gives a tuning effect to the pendulum which is proportional to the disturbing frequency, as will be shown in the following section.

DYNAMIC ABSORBER WITH A NATURAL FREQUENCY PROPORTIONAL TO THE EXCITING FREQUENCY

When the dynamic absorber is tuned to resonance ($F_2 = \omega/\omega_2 = 1$), equation (7b) becomes:

$$2\gamma_2 \sin[(\pi/2) + \omega t - \epsilon_2] = (\Phi_1/\Phi_2)\sin(\omega t - \epsilon_1) \quad (8)$$

This gives $(\pi/2) - \epsilon_2 = -\epsilon_1$, or: $\pi/2 = \epsilon_2 - \epsilon_1$.

Moreover, $\Phi_1/\Phi_2 = 2\gamma_2$

and the coupling factor becomes

$$\kappa = \mu(\omega_2/\omega_1)^2 = \mu F_1^2$$

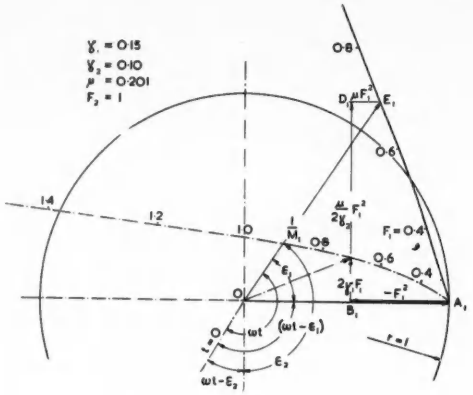

Fig. 11

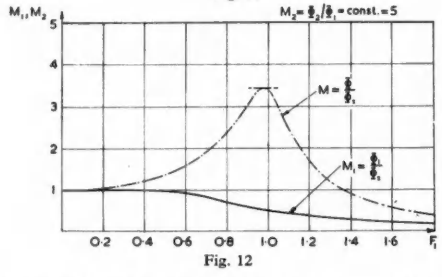

Fig. 12

Substituting these new values in eq. (7a), we obtain

$$(1-F_1^2+\mu F_1^2)\sin(\omega t-\epsilon_1)+2\gamma_1 F_1 \sin[(\pi/2)+\omega t-\epsilon_1] - (F_1^2/2\gamma_2)\mu \sin(\omega t-\epsilon_2)=(1/M_1)\sin\omega t \quad .. \quad (9)$$

This result can be expressed by means of the polar diagram of Fig. 11, which indicates the vector $OA_1 B_1 C_1 D_1 E_1$. The calculation is for an absorber with the same moment of inertia and damping γ_2 as in the previous case, but with the absorber constantly in resonance with the exciting torque.

The locus of the tip E_1 of the vector OE_1, in a system with the axes AO and AZ, is given by the equation

$$y_2+(B/2\gamma_2)^2 x^2-(B/\gamma_1)\,x\,y-(4\gamma_1^2 B/\mu)\,x=0 \quad (10a)$$

where $B=\mu/(1-\mu)$. As the discriminant of this equation is equal to zero, this gives a parabola passing through the point A, with a rather flat contour. For sufficiently large values of F_1, it can be approximated by the straight line

$$y=(B/2\gamma_2)\,x \quad .. \quad .. \quad (10b)$$

Fig. 12 shows the curve of the dynamic magnifier M_1 as a function of F_1. This curve is expressed by the equation

$$(1/M_1)^2=(1-F_1^2+\mu F_1^2)^2+[2\gamma_1 F_1+(\mu/2\gamma_2)F_1^2]^2 \quad (11)$$

Comparing this curve $M_1=\Phi_1/\Phi_2=f_1(F_1)$ with the curve $M=\Phi/\Phi_0=f_2(F_1)$, which gives the peak for the original system, we see that with the absorber the resonance peak is completely eliminated.

As regards the vibration amplitude of the pendulum mass, this is given as a function of Φ_1 (amplitude of main system) by the relation

$$\Phi_2=\Phi_1/(2\gamma_2)$$

which was obtained previously. If $\gamma_2=0{\cdot}1$, then $\Phi_2=5\,\Phi_1$. This amplitude is therefore considerable. It expresses the fact that the vibrations have practically disappeared from the main system and affect only the pendulum system. This amplitude being independent of F_1, is not greater in the former resonance region ($F_1\simeq 1$) than at other frequencies.

(To be continued)

GERMANY

The Influence of Spraying Conditions on the Grain Size of Sprayed Metal Deposits

By P. Koch. (From *Metalloberfläche*, Vol. 5, No. 9, September 1951, pp. A 129-A 133, 10 illustrations.)

Spraying conditions influence the grain size of the deposit in a rather complex manner. Various metals are sprayed on to steel sheet under conditions roughly suggested by shop experience, the results of experiments are plotted in graphs, and a general formula covering all the variables is derived from statistical interpretation and recommended for design and shop practice.

The spraying of metals onto steel surfaces for the improvement of surface hardness, corrosion resistance, or lubrication properties has become much more widespread in recent years. However, until now the properties of the deposit could not be safely controlled and accurately repeated. Although, with recent improvements in measuring instruments, the layer thickness can be checked, the grain size, grain structure, and content of impurities are still assessed by rule-of-thumb. In the following, a first attempt is made to correlate spraying conditions and the grain size of the deposit obtained.

In 44 experimental tests, the following materials were sprayed onto steel sheet: mild, medium, high-carbon, and stainless steel, wrought bronze, brass, copper, aluminium, Al-Mg alloy, and zinc. The same spray gun was used throughout, the wire of the spraying metal being kept to 0·079 to 0·083 in. diameter, and the feed varied from 3·6 to 17 fpm. The atomising air pressure, which was constant for each test, was varied from test to test within the limits of 65 and 100 psi. Oxygen and acetylene, used for melting the wire, were also kept at constant pressure during each test, but varied from test to test within the limits of 33 and 45, and 30 and 35 psi respectively. The sheet to be sprayed was placed perpendicularly to the nozzle of the gun at a distance varying from test to test between the limits of 5 and 10 in. The test conditions were thus more or less adapted to normal shop practice which, from experience, was taken to result in optimum qualities of the deposited layer. After spraying, the test specimens were ground parallel to the deposit surface, polished, and etched as required. The number of grains appearing on a frosted glass surface at a magnification of 100 to 500 was counted and the average size determined in square microns of area parallel to the deposit surface. ($1\,\mu = 1$ micron $= 10^{-3}$ mm $=$ approx. $0{\cdot}04\times10^{-3}$ in.)

Experience shows that the grain size decreases as

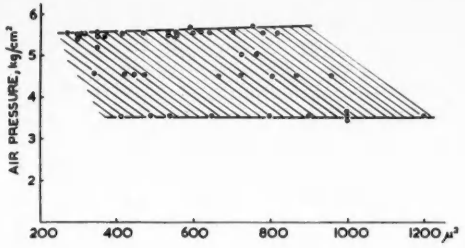

Fig. 1.

the air pressure is increased. A direct quantitative relationship, however, cannot be established, since the test results scatter considerably and do not exhibit any clear trend (Fig. 1). It may be that each spraying metal taken separately would show a more definite relationship between air pressure and grain size, but the small number of test specimens would not allow of any statistical evaluation of such qualitative trends. Moreover, a general formula covering all the metals is aimed at. Thus, in order to establish a trend that can be evaluated quantitatively, we must take into consideration other variables affecting grain size:

(1) The atomising effect depends not only on air pressure but also on the pressure of the combustion gases provided by the oxygen and acetylene. We may, therefore, plot as ordinates not the air pressure but the sum of the pressures of air, oxygen and acetylene (Σp). A certain trend is then discernible, but the scatter is still too wide for evaluation.

(2) On its travel from the nozzle to the surface to be sprayed, the atomised metal cools down and loses some of its ductility, the more so the greater the distance l between nozzle and plate. The grain size must

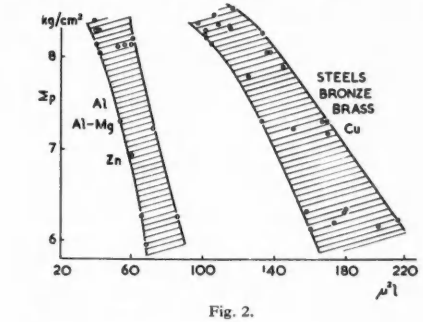

Fig. 2.

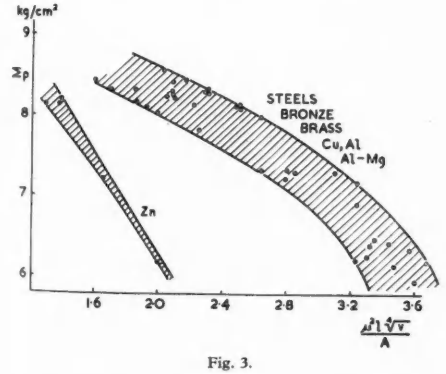

Fig. 3.

therefore vary in roughly inverse proportion to l, and we may plot in a horizontal direction the product $\mu^2 l$ (see Fig. 2). The graph can be seen to have improved considerably; evaluation would be possible, but a further narrowing of the field of scatter is desirable.

(3) The feed of the spraying metal must obviously be important, and a further improvement is obtained if the abscissa is made to represent the new product $\mu^2 l \sqrt[4]{v}$, where v is the feed of the wire into the gun within the limits indicated. The graph now indicates a definite trend, but the different metals separate into widely different groups.

(4) The specific heat of the metal in the spray influences the condition of the impinging grain. Since, for all metals, the product of specific heat and atomic weight is roughly of the same magnitude, we may, instead of multiplying the abscissa by the specific heat, divide the horizontal values by the atomic weight A. For simplicity, we may assume that the atomic weight of our alloy is roughly that of its main component, e.g., $A = 64$ for stainless steel, 56 for cuprous alloys, 27 for Al-Mg alloy. The ensuing graph (Fig. 3) is quite satisfactory; only zinc does not seem to follow the general law.

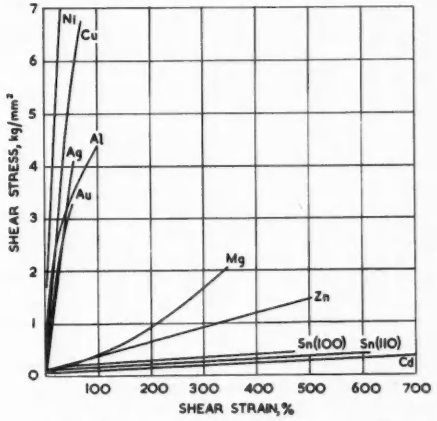

Fig. 4. **Shear-stress, shear strain diagrams for single crystals.**

(5) Finally, the deformability of the metal in the spray must bear on the grain size. Taking the diagram Fig. 4* to be representative of the deformability of single crystals, we may approximate its curves by straight lines, thus obtaining essentially two groups of metals, rigid (Fe, Cu, Al, and their alloys) and easily deformable (Zn, Sn, Cd, perhaps also Mg). If α is the angle of inclination of the straight line representing each group (tan α = ratio of shear stress to shear strain), then we may introduce the deformability of the spraying metal into our graphs by dividing the abscissa values by sin α (Fig. 5, p. 416). This new graph shows a sharply defined trend common to all the metals used in the tests and is amenable to statistical evaluation as follows.

A curve is drawn through the mean values of the field of scatter (Fig. 5) and transformed into a straight line by a change of co-ordinates. Such a change is obtained if we plot as ordinates, not Σp, but the expression $\sqrt{100 - (\Sigma p)^2}$. (Fig. 6), and certain analogous expressions in the physics of gas dynamics suggest that this purely mathematical transformation may not be

(*Concluded on page* 416)

*Schmid & Boas, Kristallplastizität, Berlin 1935, as quoted by Barrett, "Structure of Metals," McGraw-Hill, 1943, p. 299.

Experimental Research on the "Wetting Effect" and "Liquostriction"

By C. BENEDICKS and R. HÄRDEN. (From *La Metallurgia Italiana*, Vol. 43, No. 9, September, 1951, pp. 383-397, 31 illustrations.)

The "wetting effect" is the reduction or increase in strength of a solid which is in contact with a liquid. "Liquostriction" is the change in dimensions due to the action of the liquid on the solid body. This article gives the results of research work carried out in this field as well as a theory relating the "wetting effect" to surface tensions. The test equipment used is also described.

THE known fact that water facilitates the cleavage of mica led Benedicks and Ruben to investigate the "wetting effect." The results obtained are of considerable practical importance.

The direct cause of the investigation was the fracture of large bolts. An examination indicated that it was probable that these fractures were related to the presence of water condensate coming from an adjacent air vent. Tensile tests showed that some notched specimens were more apt to fracture when immersed in liquid than in a dry condition. To confirm this, fatigue tests were carried out in an ASEA laboratory from 1933 to 1938. A 13 per cent chromium stainless steel was found to have a tensile strength 30-40 per cent lower in water than in oil. A carbon steel, similar in composition to the bolt material, showed a corresponding decrease of 40-50 per cent. To exclude any possible effects due to corrosion, further experiments were carried out on glass and tempered steel. With both materials, reductions and increases in tensile strength, i.e., negative and positive wetting effects, were obtained, depending on the type of liquid used.

The tests on steel were of particular interest. The specimens of 1 × 10 mm cross-section contained 0·7 per cent silicon and 0·4 per cent manganese. The tests, made on a Chevenard micro-testing machine, showed that water, ethyl alcohol, and octylic alcohol, reduce tensile strength by 22, 13 and 16 per cent, respectively. However, a large number of liquids give an increase in strength. For instance, a solution of NaOH gives an increase of 27 per cent, benzine 18 per cent, hexane 18 per cent, heptane 12 per cent, etc. Anti-corrosive liquids produce a considerable increase in strength, of the order of 30 per cent. Finally, certain types of liquids, such as toluol, have no appreciable influence on the strength of steel.

It was found that binary tetralin-vaseline mixtures with one-third vaseline and two-thirds tetralin give a considerable increase in strength for steel. The effect is much less appreciable with a mixture of two-thirds vaseline and one-third tetralin, which also has a lower viscosity.

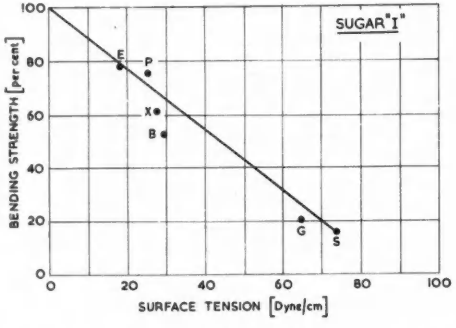

Fig. 1. **Variation in bending strength of sugar "I" due to wetting effect.**

E = ethyl alcohol; P = petroleum; X = xylol; B = benzol; G = glycerine; S = saturated solution of sugar.

The results for glass were generally similar to those obtained for steel. Other tests showed that zinc immersed in a saturated zinc amalgam also resulted in a particularly noticeable variation in strength. Thus, experimental results clearly prove the considerable influence of liquids with a wetting effect on the mechanical strength of solid materials. Therefore, the strength of a solid is not fully defined without a reference to the external medium in which it is tested.

RESULTS OF FURTHER EXPERIMENTS

Sugar: As sugar, owing to its porous structure, has a relatively large surface area, it was expected that the wetting effect would be most pronounced. Strips of sugar of 27 × 12 × 6·2 mm were tested. The strips were supported at the two ends and loaded at the centre either by a steel cylinder of 4 mm diameter or by lead spherules. Two grades of sugar were investigated, sugar "I" being refined to a greater degree of purity than sugar "II." Before application, the wetting liquids were saturated with sugar of the grade considered, in stirring

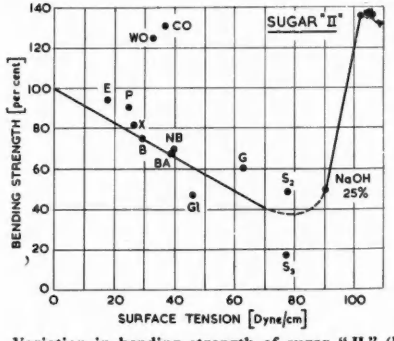

Fig. 2. **Variation in bending strength of sugar "II" (less highly refined).**

E, P, X, B, and G as in Fig. 1; WO = watch oil; CO = castor oil; Gl = Glycol; NB = nitro-benzol; BA = benzoic aldehyde; S_2, S_3 = saturated solutions of sugar; NaOH 25%.

machines. A marked wetting effect was observed (see Figs. 1 and 2).

The rupturing load decreased from 2·0 to 0·5 kg for sugar "I," and from 3·41 to 0·58 kg for sugar "II." A straight-line drop was obtained for sugar "I." For the less refined grade, there is a subsequent rise in bending strength to a value 38 per cent higher than the initial value for dry sugar. Similar increases are obtained with fatty oils (castor oil and watch oil). These can be attributed to the formation of an adsorbed layer on the surface of the solid, as in the case of lubrication.

Gypsum: Tests were carried out on ordinary gypsum consisting of 93·5 per cent $CaSO_4$–$2H_2O$, using an organic binding medium. There is a greater amount of scatter in the results (Fig. 3), but the decrease in bending strength follows approximately a straight line. Fatty oils (castor oil and watch oil) reduce the strength in the case of gypsum. However, increased strength is obtained with paraffin, which may tend to lubricate its surface.

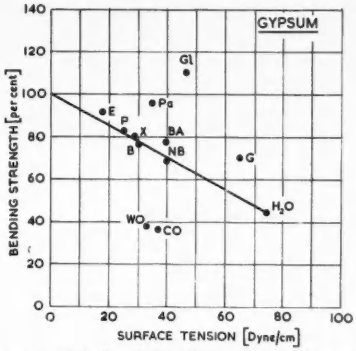

Fig. 3. **Variation in bending strength of gypsum.**
E, P, X, B, G, Gl, BA, etc. as in previous figures ; Pa = paraffin.

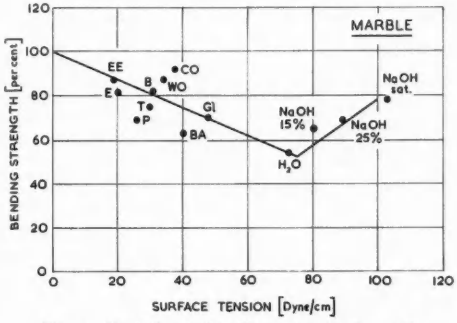

Fig. 4. **Variation in bending strength of marble.**
EE = ethyl ether ; T = toluol ; other symbols as in previous figures.

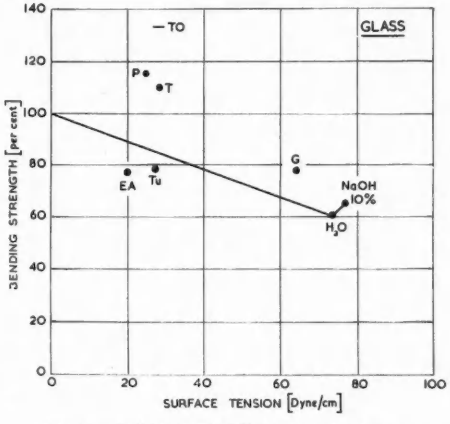

Fig. 5. **Variation of bending strength of glass.**
EA = ethyl alcohol ; Tu = turpentine ; TO = Tar oil ; other symbols as in previous figures.

Marble: White marble specimens with a cross-section of 5·0 × 9·5 mm were tested on a Chevenard micro-tester. The test results (Fig. 4) show less scatter than for gypsum. There is an approximately linear decrease down to the surface tension of saturated water (72·3 dyne/cm) and a subsequent rise as in the case of sugar "II."

Glass: Previous research had shown particularly marked reductions in strength with liquids, such as

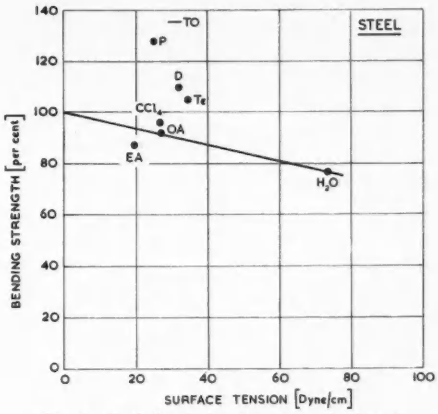

Fig. 6. **Variation in bending strength of steel.**
OA = octylic alcohol ; D = decalin ; Te = tetralin ; other symbols as in previous figures.

mercury, having appreciable cohesive forces and a high surface tension. It was therefore expected that this would also be true for liquids giving a negative meniscus, such as ethyl alcohol, turpentine, glycerine and water. Experiments confirmed that there was a linear decrease in strength with greater surface tension for these liquids. The curve rises again to a value 35 per cent higher than the initial dry value when NaOH is applied. Tar oil, for which the surface tension cannot be given, produces an increase in strength of 30 per cent. Increases are also obtained with petroleum and toluol.

Tempered steels: The results for tempered steels show a similar variation (Fig. 6). Ethyl alcohol, octylic alcohol, carbon tetrachloride and water are fairly well situated on a straight line. A considerable increase in bending strength is obtained with tar oil and petroleum, as in the case of glass. However, the slope of the curve is less steep than in the previous cases.

Polystyrol: This fragile, chemically homogeneous substance was tested on the Chevenard micro-tester. It had been stated that polystirol could not be wetted by water. The first tests with ethyl alcohol gave a reduction in strength of 77 per cent. Alcohol had no effect. Tests were then made with pure water, without the addition of wetting elements, such as tergitol. The results obtained were variable, showing reductions in strength of 14 per cent and increases up to 16 per cent. Further research will be needed to determine anisotropic influences such as the direction of the laminations in the specimens. The period of contact of the solid with water may also have some effect in this case.

RELATION BETWEEN DECREASE IN STRENGTH AND SURFACE HARDNESS

As previously observed, the slope of the straight line for tempered steel is appreciably less steep than for other materials. A comparison is given in Table I, the slope parameter (column 3) being expressed as the per cent decrease in strength occurring at an arbitrarily chosen value of 70 dyne/cm for the surface tension. The

TABLE I.

Material	Approx. hardness (Moh's scale)	Per cent decrease in bending strength at 60 dyne/cm
Steel	8·5–5·0	21·0
Glass	6·5–4·5	36·0
Marble	4·0–3·0	43·0
Gypsum	2·0–1·6	53·0
Sugar I	2·0–1·0	60·0
Sugar II	1·5–1·0	80·0

relative decrease in strength thus varies approximately as the inverse of the hardness number in Moh's scale. A graph of these results is also given in Fig. 7. The hardness of sugar was approximately estimated.

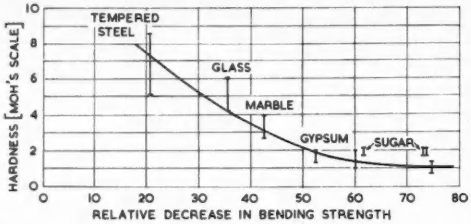

Fig. 7. **Percentage decrease in bending strength obtained by wetting effect.**

The hardness of a solid should be related to its surface tension and cohesive forces. It is thus conceivable that the method considered for determining the wetting effect and the reduction in bending strength may render possible the determination of the surface tension of solid bodies, which hitherto seemed inaccessible to experiments.

From observations so far made, it appears that from the point of view of the wetting effect, there are two types of liquids :—(i) those causing a reduction in bending strength, generally following a linear law ; and (ii) those which give an increase in bending strength. The latter are either situated on the upward extension of the straight line or distributed in a more or less irregular manner.

The first group would seem to correspond to the " non-polar " liquids for which Antonoff's law is valid, whereas the second may have a " polar " character and constitute an exception to this law.

THE CONCEPT OF SURFACE TENSION

Even to-day, the concept of the " molecular sphere of action," introduced by Laplace in 1809, is used in many textbooks to explain the existence of surface tension. At the surface, a particle has only one half of the molecular sphere and this gives rise to a cohesive force perpendicular to the surface. It is known, however, that surface tension exerts its effect within the surface, and this is not easily related to the perpendicular force. The molecular sphere of activity may have been, therefore, a useful concept, but it is only of secondary interest in regard to the subject considered in this article.

Instead, a theory with the following hypotheses is proposed for consideration :—

1. The forces of attraction can be regarded as elastic lines of force (similar to those considered by Faraday).
2. According to modern theory, the atomic nucleus is a mass consisting of neutrons and protons (nucleons). From each of these nucleons, it may be assumed that a definite number of unit forces of attraction emanate, and attract other masses.
3. If the atomic nucleus comprises N nucleons, the corresponding number of lines emanating will be equal to Nn.
4. Each force emanating from a nucleus is assumed to have a continuation in another nucleus nearby (as in the general representation of valency forces).
5. The lines of force coming from a nucleus are regularly distributed in certain " preferential " directions of space (beams of force).

For a more concrete illustration, a two-dimensional square network of nuclei, representing a regular distribution of atoms in a condensed phase, can be considered. The points in the network represent the mean positions of the nuclei. Assuming that each nucleus emits 6 lines of force in 4 directions (as in Fig. 8a), the network system can easily be extended indefinitely.

If the uppermost line of points is a surface boundary, the network will end there and the lines which would have extended upwards will now branch out laterally. Thus, using symbolic figures, there will be 9 lines of force instead of 6 joining each nucleus at the surface boundary (Fig. 8b). This is similar to the " double bond " of Kekulé, in organic chemistry.

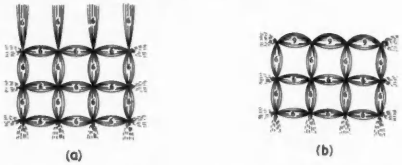

Fig. 8. **Lines of force between nuclei within a liquid and at the surface of a liquid.**

The excess of attractive forces (9 instead of 6) provides a clearer illustration of the concept of surface tension. The reasoning remains the same for three-dimensional networks or other types of regular arrangements. It also applies to irregular distributions of atoms, as in the case of liquids. Thus, any free surface of a condensed phase will have a definite excess of attractive forces.

It is frequently stated that the surface of a condensed phase behaves as if it were acted upon by an elastic skin. This interpretation should be regarded with caution. In fact, the free surface is subjected to the action of an excess of forces.

THEORY OF WETTING EFFECT

From the above, the following conclusions can be derived. When a solid body is wetted by a normal liquid, foreign atoms are added by contact, and the conditions obtained are as follows :—

(A) The surface tension of the solid body decreases (for instance, " from 9 to 6 "). This corresponds with a decrease in resistance to bending. Accordingly, it should be expected that the greater the surface tension of a solid, the greater will be its bending strength. This gives a simple explanation of the " negative " wetting effect (strength reduction). The " positive " wetting effect (strength increase) can be explained simply as the result of an increase of surface tension, due to a thin " monomolecular layer " or skin adsorbed at the surface of the solid. However, other explanations for this latter case are possible if the presence of fissures is considered at the surface of the material, which give improved cohesion when filled with a wetting liquid.

(B) It can be expected that the reduction in strength will be primarily dependent on the surface tension of the liquid. This has already been proved experimentally (see Figs. 1-6).

(C) The presence of a wetting liquid which reduces the attractive forces at the surface boundary (say, " from 9 to 6," as in Fig. 8b), should also result in a dilatation of the solid body. In fact, the thermal excitation of the atoms should produce an increase in the distance between the nuclei when the attractive forces are reduced. This little-known effect has been investigated. It has been given the name of " liquostriction." It may be expected that liquo-striction increases with the surface tension of the liquid.

The existence of liquostriction has been proved experimentally. The following section gives further details of recent research work and descriptions of the test equipment used to investigate this effect.

EXPERIMENTS ON LIQUOSTRICTION

Test equipment: Extremely small variations in length being expected, the measurements were made with the aid of a special micrometer, known as the " Microkator "

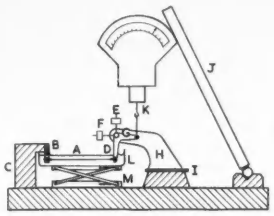

Fig. 9.
Abramson Microkator.

(Type 220A), designed by H. Abramson and manufactured by C. E. Johansson A/B of Eskilstuna. The apparatus is illustrated in Fig. 9.

The wire *A* being studied is fastened at one end to the vertical arm *D* of a bell crank arrangement mounted in jewel bearings and balanced by threaded weights *E* and *F*. The bearings are in an iron bracket *H* which is solidly fixed on the table *I* of the micrometer. The scale has 80 divisions, each of which corresponds to 0·0001 mm. The weight *f*, which can be as large as 125 grams, was generally adjusted to values between 5 and 15 gr. In the instrument used for the tests, the load was applied by a magneto-mechanical device. The quartz fibre or other material tested had a length of 210-250 mm and a diameter of 0·03-0·05 mm. An average temperature of 20° C was maintained. The load was applied by suspending a suitable weight on the hook *K* and setting the adjusting screws so that the pointer reached the middle position. The trough *L*, made of brass, contains the liquid used for the experiments. It can be raised or lowered and fixed at a required position by means of an adjustable table *M*.

Thermocouple measurements showed temperature variations not greater than 0·2° C during the first experiments on quartz fibres. Owing to slight evaporation, the liquid was also slightly colder than the wire at ambient temperature. To compensate for the heat loss due to evaporation, a small current of 0·18A was passed through the thermostatic wire which had a resistance of about 20 ohms. Various attempts were made to obtain uniform and automatic fine temperature regulation of the liquid and the adjacent air, but the results were not thoroughly successful. It may be mentioned that initial adjustment of the pointer is also possible by tapping gently on the base of the micrometer bracket.

Causes of error: (i) To avoid errors due to resetting of the zero position, the pointer must move extremely slowly while the wire is being wetted, without impinging against the graphite stops. This can be achieved by giving the wire a slight inclination (4 deg.) with regard to the horizontal, so that the wetting may occur more gradually. (ii) Capillary attraction between the vertical arm *D* and the wall of the trough *L* can be rendered inoperative by allowing a free distance of 10 mm between these two parts. (iii) Inconsistency in results may be partly attributable to sliding of the wires. The fixing of the terminal, therefore, required considerable attention. " Caulk's " sticky wax was found useful with water, but not suitable for other types of liquid solvents. The terminals were then fixed with small brass clamps. (iv) The possibility of magnetic disturbances was investigated. Tests made without a wetting liquid showed no dilatation in the absence of liquid. These and other tests served to confirm that this cause of error could be excluded. (v) It was not possible to determine the influence of the wire diameter, since sufficiently thick quartz fibres were lacking. However, Fig. 10 shows the relative elongation $\Delta L/L$ plotted against wire diameter, as obtained from four test points. The results indicate that the liquostriction effect increases considerably with smaller diameters. The diameters were examined with a microscope and the sections were found to be reasonably circular.

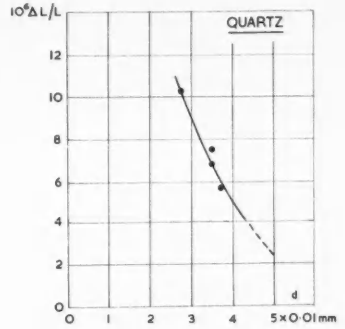

Fig. 10. **Graph showing relative elongation plotted against wire diameter.**

Effect of impurities: The smallest amounts of impurities have a considerable effect in all phenomena such as liquostriction, which depend on the condition of a free surface. Typical examples are given in Fig. 11, which shows the elongation due to wetting of quartz fibre of 0·036 mm diameter plotted against time. In Figs. 11a-d, the elongation of the fibre subjected to a given load is given for dry, wet, and subsequent dry conditions. Fig. 11a shows for the second dry period a value slightly lower than the initial value, this being due to slightly contaminated water. With further contamination, the rate of elongation is reduced, as shown in Fig. 11b. Contamination with watch oil resulted in the curve of Fig. 11c, which even shows a negative liquostriction effect (contraction). During the second dry period, the oil film on the wire breaks down and forms into separate droplets, which have only a weak effect, so that the elongation finally reaches its original value. Fig. 11d shows another curve, which is for benzol (instead of water) also contaminated with watch oil. These experiments show that the presence of impurities can lead to serious errors.

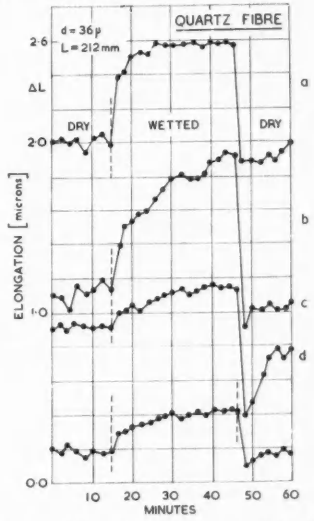

Fig. 11. **Effects with contaminated liquids.**

Inconstancy of applied load: It was found that light loads gave inconsistent results and that a load of about 5 grams was necessary to obtain good constancy in the load applied by the apparatus. Tests were extended to

40-hour periods to determine optimum load conditions and arrangements that were insensitive to slight inevitable disturbances due to traffic.

Various loading devices were tried in place of the magneto-mechanical astatic spring system, in order to obtain a constant applied load with less complication. A purely elastic device, practically without friction, was tried but gave insufficient sensitivity, being without an astatic arrangement. A simple and sensitive lever device was employed by Tenow for tests of the liquostrictive effect on copper. Finally, a new "surface balance" type micrometer, maintaining the load absolutely constant, was received from Johansson A/B but has not yet been extensively applied.

The results obtained show that friction in the loading apparatus becomes appreciable below 2 grams, whereas it is relatively less important at higher loads. Theoretically, it was expected that liquostriction would be slightly greater at low loads. Tests made with applied loads of 4, 2 grams, and 1 gram gave some confirmation of this point, but the scatter for loads in the region of 1 gram was such that a definite opinion cannot be given.

LIQUOSTRICTION EFFECT WITH QUARTZ FIBRES

When the wetting action is exerted by pure, recently distilled water, an elongation of the fibre is generally obtained. A typical example of tests on quartz fibres (d = 0·036 mm, L = 212 mm) is shown in Fig. 12.

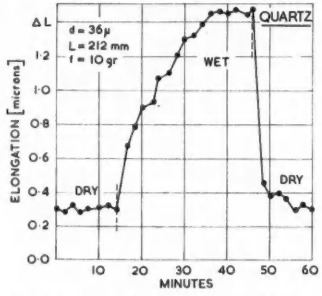

Fig. 12. **Liquostriction effect of quartz fibre in water.**

A load of 10 grams was used, giving an additional elongation of 0·0012 mm after wetting, at 20·5° C. The slow rate of extension is probably due to the considerable time required for wetting, when the specimen has been kept dry for a certain period. Further tests showed that the rate of dilatation is increased if the object has remained dry in air for only a comparatively short time. Tests made with different loads showed remarkably small variations in elongation due to wetting effect. In some experiments, it was found that the elongation due to wetting did not decrease down to the initial value after drying, unless a slightly smaller load was applied. This secondary effect will still require further investigation.

METALS AND VARIOUS ALLOYS

Invar: An invar wire of 0·05 mm diameter gave a mean relative elongation $\Delta L/L$ of 6·6 × 10^{-6}.

Platinum: A cold-drawn platinum wire was tested and the mean value obtained was 7·5 × 10^{-6}. After this test, the wire was dried and heat-treated in air. A subsequent test showed that the rate of elongation had not increased, contrary to the result previously obtained with a quartz fibre. The explanation is that air absorbed at ordinary temperatures is more easily removed by water at ordinary temperatures and penetrates less deeply into the metal than at high temperatures.

Iron: Tests of iron wire 0·51 mm in diameter were carried out in water and ethyl alcohol. As expected, the rate of wetting was appreciably higher with the latter liquid. When the liquids were contaminated with oil or other impurities, the value for the second dry period was found to be higher than the initial dry value.

Steel: The steel wire of 0·51 mm diameter was tested in water and ethyl alcohol and in both cases gave a smaller liquostrictive effect than iron wire. The elongation in ethyl alcohol is, moreover, definitely less than that in water.

Nickel: The wetting effect was rather slow, and somewhat similar to that of the heat-treated platinum. It may be noted that both platinum and nickel are active contact surfaces, this being also the case with copper.

Copper: Ordinary electrolytic copper and galvanometer-wire copper free from iron were tested, both in their original condition and after heat treatment in vacuo. It was found that the heat-treated specimens show a greater liquostrictive effect than the untreated ones. This can be related to the fact that under vacuum an occlusion of gas is impossible. The liquostriction of the purer copper (7·2 × 10^{-6}) was slightly less than that of ordinary copper (8·1 × 10^{-6}) which contains a small amount of iron. Although the quantity of iron is very small, it is localised generally on the surface of the copper wire as a result of the drawing process. The iron, with its relatively higher liquostriction, can thus have a comparatively greater effect on the phenomenon due to surface action.

CONCLUSIONS

The values of liquostriction obtained for metallic materials (wires of 0·051 mm diameter) do not differ greatly from one another. The mean value is approximately $\Delta L/L$ = 7·7 × 10^{-6}. For quartz fibres, extrapolation to a diameter of 0·051 mm gives a lower value of approximately 2·5 × 10^{-6}. The highest value observed is that for iron (10·0 × 10^{-6}), although steel (7·2) is somewhat lower. Steel, nickel, and pure copper without iron, give a similar value of 7·2 × 10^{-6}, whereas copper with a slight iron content on its surface reaches 8 × 10^{-6}.

The above observations indicate that the liquostriction effect of various elements is a property subject to relatively small variations. In this respect, the results are quantitatively analogous to those obtained for atomic heat: Si = 3·8; O = 4·0; and for most metals: 6·4.

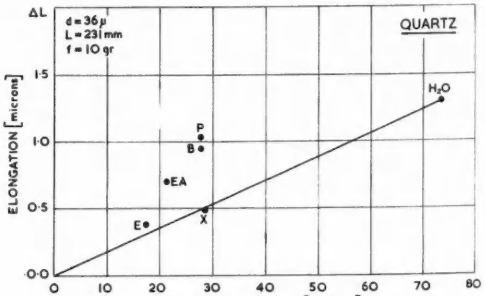

Fig. 13. **Liquostriction effect for quartz fibres.**

The detailed results for quartz fibres (Fig. 13) show that the liquostriction effect depends on the surface tension of the ambient medium. The highest effect is obtained for water (73 dyne/cm). The tests of iron and steel in 99 per cent ethyl alcohol gave values (7·4 × 10^{-6} for iron and 4·2 × 10^{-6} for steel) which are higher than expected from the linear law, possibly owing to absorption of water at the wire surface, which may occur to a greater extent on iron than on steel.

CLASSIFIED ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns, are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

BOLTS AND NUTS

The Fatigue Strength of Threaded Connections

By R. C. A. THURSTON. (From *Transactions of the ASME, U.S.A.*, Vol. 73, No. 8, November 1951, pp. 1085-1092, 8 illustrations.)

PUBLISHED information on the strength of threaded connections subjected to dynamic loading has been surveyed and summarised, with particular reference to high-duty applications. After a consideration of the load distribution and the concentration of stress at the thread roots, the subject is discussed from the following points of view : Effect of thread form ; effect of method of manufacture ; effect of degree of tightness ; methods for improving performance ; special modifications in design. In general, the basic principles to be followed in the design of high-strength bolt and stud assemblies are outlined, the reasons underlying them explained, and evidence in their support given whenever possible.

Many factors are involved, some metallurgical, some geometrical, some in the manufacturing procedure, and some in the assembly. Probably the most important individual factor is the necessity for ensuring and maintaining sufficient tightness, but the neglect of any one factor may be responsible for a fatigue failure. Provided due attention is paid to the basic principles brought out in the text, little difficulty should be experienced in obtaining an efficient design.

ELECTRONICS

Circuit Printers for Flat and Cylindrical Surfaces

(From *Technical News Bulletin* of the *National Bureau of Standards, U.S.A.*, Vol. 35, No. 11, November 1951, pp. 168-170, 4 illustrations.)

Two semi-automatic machines for printing electronic circuits, one for flat surfaces and the other for cylindrical surfaces, have recently been developed by Robert L. Henry and associates of the NBS engineering electronics laboratory. Such printers seem to offer two important advantages. First, they are faster than hand printers and more economical for use in quantity production. Second, and perhaps equally important, they give a more uniform product.

The NBS printer for flat plates is motor-driven and more fully automatic than the printer for cylindrical surfaces. In the flat-plate printer, a turntable accepts the unprinted plate at a loading position, carries it to a printing position, then carries the printed plate to an unloading position, where it is automatically flipped into a chute.

In regular operation, three plates are processed simultaneously : While the first plate is unloaded, the second is printed, and the third is loaded. The turntable stops while these operations are performed, advances the plates one-third of a revolution, stops again, and thus continues the sequence. The usual production rate, about 1,000 plates per hour, can be increased to 1,500 per hour without loss of printing quality, but at the expense of excessive wear and tear on the machine.

The cylindrical-surface printer was developed for the printing of cylindrical ceramic forms less than one-half inch in diameter. Such small ceramic cylinders are usually out-of-round and present a much more difficult problem than larger, more perfect, forms.

The cylindrical-surface printer is loaded manually by slipping the cylinder to be printed over a mandrel. A single stroke of a hand-operated control lever then puts the machine through the entire printing cycle and operates a release mechanism, which drops off the printed cylinder.

With hand loading of the cylindrical surface printer, an operator can easily print 1,500 cylinders in an 8-hour day. An automatic feed mechanism and electric drive, which could be added without much difficulty, should increase the production rate to a probable 500 or 1,000 cylinders per hour. For fully automatic production at high speed, a conveyor belt system with steadying pins could also be added to carry away the printed cylinders.

ELECTRICAL ENGINEERING

New Views on Oxidic Semi-Conductors and Zinc-Sulphide Phosphors

By E. J. W. VERWEY and F. A. KRÖGER. (From *Philips Technical Review, Holland*, Vol. 13, No. 4, November 1951, pp. 90-95, 3 illustrations.)

FOLLOWING upon a brief discussion of the semi-conducting elements silicon and germanium and of non-stoechiometric oxidic semi-conductors, the " method of controlled valency " is described by taking nickel oxide as an example. This method consists in bringing about desired changes in valency by the admixing of suitable " impurities." There is a great similarity in the mechanism of conductance between non-stoechiometric semi-conductors and other semi-conductors prepared by the method of controlled valency. Compared with the former, the latter group, however, possesses great advantages, which are to be ascribed to the lack of thermal stability of non-stoechiometric compounds. This lack of stability is due to the fact that in non-stoechiometric compounds there are always vacant sites in the lattice.

Somewhat similar considerations apply to zinc-sulphide phosphors. After the part played by halogen ions in the formation of these substances had been realized, a better picture could be formed of the fluorescent centres : the centres are formed by an activator ion surrounded by sulphur ions. The accuracy of the hypothesis developed finds confirmation in the possibility of having the part played by the halogen ions taken over by trivalent cations. This opens the way to the production of entirely new phosphors.

METALLURGICAL ENGINEERING

Colour Etching in Vacuo of Metal Specimens at High Temperatures

By N. T. GUDCOV and M. G. LOZINSKIY. (From *Hutnické Listy, Czechoslovakia*, Vol. 6, No. 5, 1951, p. 91, 1 illustration, originally published in *Zavodskaya Laboratoriya, Russia*, Vol. 16, No. 9, 1950, pp. 1072-1073.)

DURING the last few decades, increasing interest has been shown in methods which permit of studying the microstructures of metals and alloys at high temperatures. For this purpose, heating of the metal specimens in vacuo, at a pressure of about 10^{-5} mm mercury column, to temperatures of 900 to 1100° C is particularly suitable. In this procedure, traces of air still remain and the

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oxygen contained therein forms a fine oxide film on the surface of the specimen, this film remaining preserved during the process of cooling to the normal room temperature at which microscopic investigations are carried out. The apparatus described in this article permits of obtaining a vacuum of 10^{-5} mm mercury column and a maximum temperature of 1200° C with a heating rate of about 20° C/minute and a cooling time in the furnace of about 2½ hours. A colour photograph of an Armco steel specimen which was kept at a temperature of 1100° C for 30 minutes is given as an example. The typical appearance of the austenitic structure remained preserved in the oxide film; the areas of some grains appear blue and those of other grains appear straw-yellow or reddish owing to the difference in thickness of the individual parts of the oxide film, which, in turn, is due to the anisotropic effect of the individual crystals.

INSULATING MATERIALS

Winding-Insulation Testers

By N. ROHATS and E. C. SCHROM. (From *General Electric Review, U.S.A.*, Vol. 54, No. 9, September 1951, pp. 51-55, 6 illustrations.)

THE various types of winding-insulation testers for the testing of coils and complete windings of rotating machines which are described here are the results of steady progress over the past nine years or so. Wherever applied, they usually showed a fairly high rate of rejection. This, however, has led to better manufacturing methods, by which rejections were reduced to a small fraction of one per cent, resulting in a more uniform and reliable product. Used in the development laboratory, they have led to large savings by helping to devise more economical systems of insulation. Further developments along these lines may be expected in the future.

WELDING

Pressure Welding Aluminium at Various Temperatures

By M. A. MILLER and G. W. OYLER. (From *The Welding Journal, U.S.A.*, Vol. 30, No. 10, October 1951, pp. 486s-498s, 23 illustrations.)

PRESSURE welding, as used in this paper, is defined as the formation of a solid-phase weld between metallic materials, by the application of a deforming pressure, at any temperature below the melting point of the components. It has been shown that the three major factors in the pressure welding of aluminum, assuming optimum surface preparation and suitable die design, are temperature, pressure and time. These factors are closely interdependent and capable of graphical representation.

At temperatures below about 500° F, the extent of deformation during welding, largely established by the unit pressure, determines weld efficiency. At elevated temperatures, diffusion is also an important factor in the establishment of metallurgical bonds. This has been shown by photomicrographs of joints between dissimilar aluminium alloys. As a consequence, unit pressures decrease rapidly as temperatures increase above 600° F and approach the solidus temperature of the alloy being welded. Selected published information has been correlated with the data obtained during this investigation in order to illustrate the fundamental principles involved in the pressure welding of aluminium alloys.

The Use of Welding in the Assembly of High-Pressure Boilers

By M. I. KHOLMOGOROV. (From *Avtogennoe Delo, Russia*, Vol. 22, No. 2, February 1951, pp. 24-27, 4 illustrations.)

DRUM-TYPE water tube boilers used by the U.S.S.R. State Electricity Undertakings (1700 psi pressure, 510° C steam temperature) have welded joints for all tubes, the latter being expanded into the drums. Hitherto, the boiler makers used flame welding exclusively, but it was desired to make an attempt to use arc welding, which was found to be superior to flame welding both in regard to attainable weld strength and structure of the material. The boiler passed all its standard hydraulic tests without complaint. Arc-welding appears to be quite feasible for small diameter tubes, provided the necessary thin electrodes (0·078 to 0·098 in.) are obtainable and the welders suitably trained. The further expansion of arc welding seems to depend on the availability of such thin electrodes (0·078, 0·098, and 0·118 in.) of suitable quality for welding alloy steels.

THE EFFECT OF FERROMAGNETIC MATERIAL ON THE EXTERNAL CIRCUIT OF A RESISTANCE WELDER

(*Concluded from page* 402)

between them, the coefficient of mutual induction will be found to be greater than zero: the real inductance increases, while the coefficient of mutual induction varies inversely as the span or gap between the conductors, thus also decreasing the effect of the ferromagnetic body introduced. This analysis further demonstrates that, theoretically, the inductivity of the circuit will vary with the width, but not with the thickness, of the ferromagnetic body introduced, i.e., not with the mass, but with the linear dimensions or configuration of the body introduced. The location of the introduced body within the circuit is found to be of little consequence; a body located outside the circuit has little effect and, at most, affects the induction in the nearest conductor. These theoretical conclusions have been confirmed by experimental results obtained from tests with circuits of such simple form, introducing steel sheets (also Permalloy) of varying length, width, and thickness. The experimental results thus refute the opinion hitherto held that the mass of the ferromagnetic material introduced is decisive for its influence on the parameters of the welding circuit. The shape or configuration of the body introduced, on the other hand, is found to be decisive, the cross-sectional area being likewise immaterial. Further tests have been made on the influence of the position of the ferromagnetic body in the circuit. These have shown the positioning of the body to be of little influence, however considerable the resistance in the circuit. Bodies placed outside the circuit also have little effect. The small increase observed when the body is placed close to one or the other electrode of the circuit can be explained by the increased induction of the nearest circuit conductor element. Tests made to determine the effect of width and thickness of the introduced plates showed that the resistance of the circuit increases to the same extent as that by which the introduced body fills the electrode gap. These experiments, while confirming the theoretical result and refuting the opinions hitherto held in regard to this problem, have shown a considerable quantitative divergence from the results of theoretical calculation. This is to be explained by an increase in the active component of the circuit resistance by the introduction of a ferromagnetic body: it will be recalled that an alternating magnetic flux in a ferromagnetic body is accompanied by eddy and hysteresis losses, which increase the active resistance of the system. This is confirmed by the phase shift observed between current and voltage in the primary and secondary circuits respectively. Analysis of a number of recorded oscillograms shows, however, that the introduction of a ferromagnetic body not only fails to increase the phase shift, but even decreases it, indicating a faster rate of increase of the active component compared with the reactive resistance component. Even an experiment with Permalloy, a material of high permeability and low coercive force, did not detract from this conclusion.

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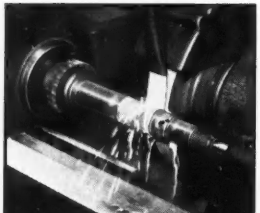

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Shell *Dromus* Oil

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NEWS OF THE MONTH

PERSONAL

Three promotions to the rank of Chief Scientific Officer in the R.N. Scientific Service have been announced recently. They are of **Mr. J. Anderson, C.B.E., M.I.E.E.,** formerly Chief Scientist at H.M. Underwater Detection Establishment, Portland, and now Chief Scientist at the Admiralty Signal and Radar Establishment, Haslemere; **Colonel A. V. Kerrison,** formerly Superintendent of the Admiralty Gunnery Establishment, Teddington, and now Director of Aeronautical and Engineering Research, Admiralty; and **Dr. E. C. S. Megaw,** formerly Superintendent of Research at A.S.R.E. Haslemere, and now Director of Physical Research, Admiralty.

Mr. W. S. Bates has been appointed a director of Philip & Son Ltd., Dartmouth.

Sir David Brunt, M.A., Sc.D., F.R.S., Professor of Meteorology in the University of London, at the Imperial College of Science and Technology, and Vice-President and Secretary (Physical) of the Royal Society, has been appointed a director of The Fulmer Research Institute Ltd., Stoke Poges, Bucks.

Mr. J. C. Carr, C.B.E., has been appointed, on his retirement from the post of principal assistant secretary in the Ministry of Supply, to the Board of Thomas Summerson & Sons Ltd., Darlington, and their subsidiary companies.

Mr. Henry D. Challen, A.M.I.Mech.E., director of Taylor & Challen Ltd., has been re-elected chairman, and **Mr. A. E. Whyman,** chairman and managing director of E. W. Bliss (England) Ltd., vice-chairman, of The British Power Press Manufacturers' Association, Standbrook House, Old Bond Street, London, W.1.

Mr. Gilbert Dodd has been appointed deputy manager of the purchasing department of Monsanto Chemicals Ltd., Abford House, Wilton Road, London, S.W.1.

Mr. M. Gaughan, B.Eng., A.M.I.E.E., F.I.E.S., has been appointed to the Government and Railways Department of the BTH Lamp and Lighting Department at Mazda House, Fitzroy Road, London, N.W.1.

Mr. James Grant has been appointed manager of the Shell Haven refinery, Essex, of the Shell Petroleum Co. Ltd. **Mr. R. W. J. Smith** whom Mr. Grant succeeds, has returned to a head office appointment in London. **Mr. D. B. Vale, O.B.E.,** has been appointed manager of the fuel-oil general department in succession to **Mr. J. L. Flanagan** who is retiring on December 31.

Mr. S. R. Halsey has been appointed a director of James Gordon & Co. Ltd., Dalston Gardens, Stanmore, Middlesex.

Mr. W. R. Jones has been appointed chief engineer of the Nevelin Electric Co. Ltd.

Mr. L. H. Leedham, M.I.Mech.E., superintendent of works and general services at the National Gas Turbine Establishment, has been appointed Assistant Director of Aircraft Production Development, Ministry of Supply.

Mr. H. M. L. Lewis, M.A., has been co-opted to the board of executive directors of Crompton Parkinson Ltd.

Mr. John Long has been appointed London manager of Head Wrightson & Co. Ltd. in succession to **Mr. Selby Robson.** Mr. Robson remains a director of the company and of Head Wrightson Processes Ltd.

Mr. Alexander McEwan, M.I.Struct.E., has been appointed a director of Chamberlain Industries Ltd., Staffa Works, Leyton, London, E.10.

Mr. C. F. Montgomery has been appointed general works manager of Remington Rand Ltd., Weybridge.

Mr. A. E. Shave, A.M.I.C.E., A.M.I.Mech.E., has been appointed supplies officer of the London Transport Executive.

Mr. M. W. Shorter, director and general sales manager of Westinghouse Brake and Signal Co. Ltd., has been appointed to the board of W. R. Sykes Interlocking Signal Co. Ltd.

Mr. C. St. Vincent Smith, M.I.Mech.E., has been appointed a director of Richard Garrett Engineering Works Ltd., Leiston, Suffolk.

Commander (E) T. J. Turner, R.N. ret., A.M.I.Mech.E., has been appointed general manager of Prat-Daniel (Stanmore) Ltd., Dalston Gardens, Stanmore, Middlesex.

Mr. E. B. Watton, A.M.I.E.E., lately assistant editor of "Electrical Times" has been appointed editorial assistant to **Mr. G. M. C. Peacock,** publicity manager of Babcock & Wilcox Ltd., Farringdon Street, London, E.C.4.

WILLIAM BAYLEY PARKER, F.I.C.

We regret to announce the death, on the 12th October, 1951, of Mr. W. B. Parker, F.I.C., who had retired from the British Thomson-Houston Company in 1946, after 44 years service. Mr. Parker was the Company's Chief Chemist and Metallurgist from 1902 until 1943, when he was appointed BTH Consultant Chemist and Metallurgist.

BUSINESS NOTES.

Airspeed Precision (London) Ltd. announce the opening of a new additional aircraft design office under the direction of Mr. H. J. Sims, A.R.Ae.S., at High Street, Whitton, Middlesex.

Aluminium Wire & Cable Co. Ltd. announce the opening of a Midlands branch office at Great Western Buildings, 6 Livery Street, Birmingham 3. Telephone No.: CENTRAL 5370.

The British Aluminium Co. Ltd. announce that their head office has removed to Norfolk House, St. James's Square, London S.W.1. Telephone No.: WHITEHALL 7868.

British Insulated Callender's Cables Ltd. announce that their Hull office has removed to 199 Anlaby Road, Hull. Telephone No.: Central 16367.

The Brush Electrical Engineering Co. Ltd. has acquired a 31% interest in Diesel Equipment Co. Ltd. of Vancouver, Canada. This company will act as sales organisation for Vivian Diesels and Munitions Ltd. and Vivian Engine Works Ltd., the two Brush ABOE Group subsidiaries with factories in Vancouver, manufacturing engines of 35-600 bhp and generating sets of 20-400 kW.

The Fairey Aviation Co. Ltd., Hayes, Middlesex, announce the change of name of their Australian subsidiary company to Fairey Aviation Co. of Australasia Pty. Ltd., Box 41, P.O. Bankstown, New South Wales.

Fina Petroleum Products Ltd. have removed to 25 Victoria Street (South Block), London, S.W.1. Telephone ABBEY 7822.

Ford Motor Co. Ltd., Dagenham, Essex, announce that, because of the world-wide distribution of its products, genuine Ford parts and accessories supplied by the company for such products, will be marketed in the future under the distinguishing trade mark 'EnFo.'

The Gauge and Tool Makers' Association announce that The Rt. Hon. Duncan Sandys, His Majesty's Minister of Supply, will be guest of honour and chief speaker at the next quarterly luncheon of the Association, which will take place at the Savoy Hotel, London, on Wednesday, February 20th, 1952, at 12.30 for 1 p.m.

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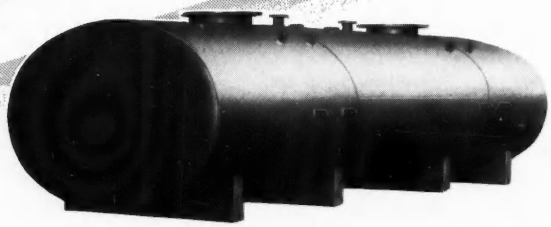

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W/23

Alfred Herbert Ltd., Coventry, have acquired controlling interest in the Sigma Instrument Co. Ltd., Letchworth.

Manchester Oil Refinery Ltd. announce that a new expansion programme is now being carried through. As announced by Mr. H. Stuart Ebben, chairman of the company, the throughput of the refinery would be increased to 150,000 tons per annum, compared with the war-time figure of about 70,000 tons and the 1950/51 figure of 115,000 tons per annum.

Construction work is already going ahead on a new 3,500 bbl/day atmospheric distillation unit. The new unit, which will work in conjunction with the existing vacuum distillation unit, will consist mainly of a fractionating tower approximately 120 ft. high. It will extend the existing range of M.O.R. products by producing white spirit and other petroleum solvents as well as petrol.

Hoover (Electric Motors) Ltd., Cambuslang, near Glasgow, will nearly double the size of their original factory by bringing an extension, now being built, into operation early next year. Of the fractional horse power motors produced at present, over 60 per cent are exported to more than 50 countries all over the world.

Monks & Crane Ltd., Stanhope Street, Birmingham 12, announce that the Telephone Number of their Head Office has been changed to CALthorpe 1381 (5 lines). The Manchester Office of the Company is at Manchester Old Road, Rhodes, Manchester.

Startrite Engineering Co. Ltd. announce that they have recently taken over a new factory at Gads Hill, Gillingham, Kent, where light woodworking machines and ½" capacity drills will be manufactured.

Steel Nut and Joseph Hampton Ltd., All Saints Road, King's Hill, Wednesbury, have acquired the plane and spokeshave business of W. S. Manufacturing Co. Ltd., Sheepcote Street, Birmingham 15.

FUME AND SMOKE EXTRACTION TRAILER FOR FIRE FIGHTING

Woods of Colchester Ltd., at the request of the Ministry of Works, have built a prototype smoke extractor using a 15 inch diameter aerofoil fan driven by a Buxton tested flameproof motor suitable for operation in all Group II gases and vapours.

Owing to its aerodynamic efficiency, this compact unit has an extraction capacity about four times that of earlier types of fan employed for this purpose. The motor and impeller are mounted in a portable steel housing provided with lifting handles. Two men can carry the fan with case and its compact size—17 inches by 17 inches enables it to be manoeuvred in a confined space. During transport the fan is carried in a cradle on a two-wheeled trailer equipped with a petrol driven generator set. On arrival at the building on fire the fan is lifted from its cradle and carried into the building. The electrical connection is provided by a length of cable run out from a spring loaded spool situated on the trailer.

THE INFLUENCE OF SPRAYING CONDITIONS ON THE GRAIN SIZE OF SPRAYED METAL DEPOSITS

(*Concluded from page* 407)

without its physical background. Fig. 6 now represents all the relevant data in a simple form in a co-ordinate system

$$x = \frac{\mu^2 \sqrt[4]{v}\ l}{A \sin \alpha}, \text{ and } y = \sqrt{100 - (\Sigma p)^2}.$$

We first calculate the arithmetic mean of all the test values $x_1, x_2 \ldots$, and $y_1, y_2 \ldots$, and obtain $x_m = 2{\cdot}52$, $y_m = 6{\cdot}17$. The correlation coefficient

$$r = \frac{\Sigma (x - x_m)(y - y_m)}{\sqrt{\Sigma (x - x_m)^2 (y - y_m)^2}}$$

can then be calculated if the x and y are taken to be the co-ordinates of the single test points in the graph Fig. 6. The resulting value $r = 0{\cdot}936$ proves that the straight-line relationship is not just accidental ($r = 0{\cdot}442$ would be the limit of an accidental correlationship). The regression coefficient

$$R = \frac{\Sigma (x - x_m)(y - y_m)}{\Sigma (x - x_m)^2}$$

indicates the true position of the mean straight line in the chosen co-ordinate system and is here $R = 1{\cdot}474$,

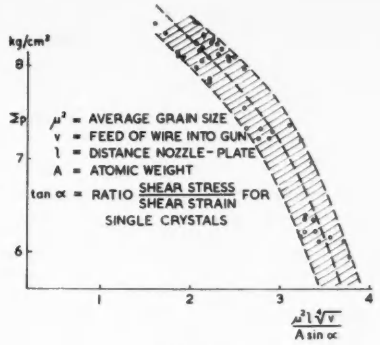

Fig. 5.

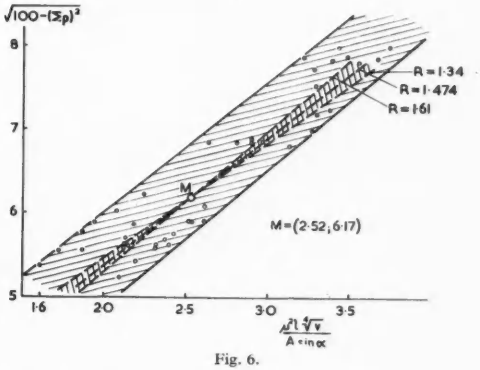

Fig. 6.

the mean error in this value being

$$e_R = \frac{\Sigma (y - y_m)^2}{\Sigma (x - x_m)^2} \sqrt{\frac{1 - r^2}{n - 2}} = 0{\cdot}1327,$$

where n is the number of test results. R thus varies from 1·34 to 1·61. The final relationship of all the test variables can now be derived from Fig. 6:

$$y = (R \pm e_R)\, x = (1{\cdot}474 \pm 0{\cdot}133)\, x$$

or substituting the actual expressions for the co-ordinates x and y of Fig. 6,

$$\sqrt{100 - (\Sigma p)^2} = (1{\cdot}474 \pm 0{\cdot}133)\ \frac{\mu^2 l \sqrt[4]{v}}{A \sin \alpha}$$

The average grain size of the deposit can finally be determined from the spraying conditions by the formula

$$\mu^2 = \frac{A \sin \alpha}{1{\cdot}474 \pm 0{\cdot}133} \sqrt{\frac{100 - (\Sigma p)^2}{\sqrt{v}\, l^2}}.$$

The above formula cannot be more than a first approximation and must still be investigated more fully. For example, the values l and $\sqrt[4]{v}$, although improving the statistical evaluation, have only a small influence and need not necessarily be introduced; the feed v is proportional to the volume of metal sprayed, and the grain size might therefore be expected to be proportional to v; the formula covers all the metals tested, but closer statistical examination reveals that there is still a slight difference between the three groups: zinc, light metals, and the rest. Nevertheless, with the above formula, a first attempt may be made to determine the grain size in advance and to reproduce a desired grain size under various spraying conditions.

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SUCTION WINGS ON POROUS 'PLANES

Aircraft designers are experimenting with wings which have porous-metal surfaces and suck the outside air into the wing during flight. The object is to reduce turbulence caused by skin friction. This will cut down drag and mean more speed and range. Experts believe that in spite of streamlining, there is still too much drag on modern aircraft.

Suction-wing models have already been tested in wind tunnels and sections of wings have been flown in the air. Full-scale flight tests may not be far off.

As present-day aircraft fly through the air, the very thin layer of air nearest the surface of the wing tends to become turbulent soon after passing the leading edge—and causes drag.

Designers are now concentrating on keeping the boundary layer smooth across virtually the whole wing—and they believe the suction-wing may be the solution to their problem.

The wing extracts some of the boundary layer air through the porous-metal and so stops it from becoming turbulent. The technique will probably be to put strips or panels of porous-metal—a sintered bronze—at the critical points along the wing. If successful on wings, the suction technique may be used over the entire surface of the aircraft.

Aircraft of the future may have these suction-surfaces, and, if the experts are successful, a 'plane may fly a quarter as far again on the same amount of fuel.

SCALE MODEL OF PYRMONT BOILER PLANT

A half-inch scale model of the high pressure water tube boiler plant nearing completion at Pyrmont Power Station, Sydney, New South Wales, is now on exhibition at the London Offices of International Combustion Ltd., Nineteen Woburn Place, W.C.1. It faithfully reproduces the boiler plant in every detail.

The Pyrmont Plant is the largest high-pressure, water tube boiler plant in the Southern Hemisphere, incorporating boilers each having a capacity of 430,000 lbs. of steam per hour, at a pressure of 1,280 lbs. per square inch, and a steam temperature of 950° F.

After being displayed in the principal Australian cities, the model will then be used for instructional purposes in the Commonwealth, and it is expected to arouse a great deal of interest among power station personnel.

NEW HIGH-ACCURACY DRIVE FOR SPINNING SYNTHETIC YARD

The General Electric Company, of Schenectady, N.Y., has announced development of a new drive for spinning machines that is designed to provide greater uniformity of denier and dye-ability of synthetic yarns than ever before obtainable.

This all-AC drive insures uniformity through the most precise speed control (one tenth of one per cent over a 7·1 speed range) ever obtained for spinning machine motors, according to G-E engineers.

The system utilizes an electronically-regulated AC adjustable-speed motor, which drives a variable frequency alternator through a two-speed, herringbone gear box. The alternator output is delivered direct to small, synchronous motors on the spinning machine. These motors, in turn, provide direct drive to the machine positions, and eliminate troublesome and costly gearing, tapes, and line shafting.

Requiring only about two-thirds of the floor space needed for a comparable DC drive, the new system provides greater operational efficiency with fewer electric machines. Lower miantenance expenses and savings in power consumption are other major advantages.

HARWELL INSTALS FIRST ATOMIC HEATING SYSTEM

Britain now has the first atomic central heating plant in the world.

It is at the Ministry of Supply Atomic Research Establishment, Harwell, where a building containing eighty offices is drawing its heat direct from BEPO, the large experimental atom pile.

Tests with the new installation have been completely successful. Eventually two, and perhaps three, more buildings will also have "atomic radiators" and the Ministry's coal consumption will be cut by at least a thousand tons a year. After counting all incidental expenses, the saving in cash is estimated at £2,650 a year. Costs of the installation amount to £15,000.

The constant hot water which will flow through the pipes is obtained by placing a heat exchanger in the outlet air duct of the pile's air cooling system. Here there is a by-pass fitted with a damper which can be adjusted to vary the proportion of the air flow passing through the heat exchanger. Hot water from the exchanger is then circulated in a closed circuit by a small pump to a secondary water-to-water heat exchanger. This supplies hot water for space heating and domestic hot water supplies.

At present the air temperature at the primary heat exchanger is 135 degrees Fahrenheit, and the water itself is heated to 130 degrees. In 1952, when modifications to the pile have been completed, these temperatures will be substantially increased.

There is no danger from radio-activity and the water can safely be used for washing.

The heat output designed for the first building is one million British Thermal Units per hour, equal to about two hundred electric fires, but for the final installation the maximum output will be 7,000,000 BTU per hour. The total floor area now being heated is 32,000 sq. ft. and the volume of space is 330,000 cu. ft.

When the system is extended to include other buildings no other heat exchanging apparatus will be required, and it will only be necessary to connect the piping.

The installation was carried out by the Ministry of Works in collaboration with the Engineering Division, A.E.R.E. The heat exchanger, measuring 10 ft. by 10 ft. by 2 ft. 6 ins. weighs eight tons.

METAL FINISHING PRODUCTIVITY REPORT

The Team's investigation covered paint finishing and electroplating, including certain related processes such as anodising, bright dipping and metal colouring. Twenty-one factories were visited and the itinerary was designed to cover a representative selection of metal-finishing plants ranging from the small jobbing shop to the largest mass-production units in the motor-car industry. Sections of the Report deal with metal pre-treatment; mechanical polishing; application methods; plant and equipment; specifications and testing; design in relation to finishing; research; safety; and management/labour relations.

The conditions of economic prosperity and free marketing in the U.S. have led to keen competition. The value of an attractive finish in promoting sales is generally recognised by American producers. Thus, finishing departments and personnel enjoy a good status in American factories. Owing possibly to the greater proportion of technically knowledgeable people at the higher levels, there seemed to be a greater appreciation by management of the technical viewpoint than usually prevails in this country. "There was a refreshing boldness in planning and a readiness to tear out and replace obsolete plant as soon as a watertight case had been made for scrapping it."

All ranks in industry appear to be cost-conscious and management frequently disseminates cost data to all supervisory grades. In some cases the operators also are kept aware of certain aspects of departmental costs and of the cost of new equipment provided for them. The American worker takes a pride in operating an expensive machine and appears to have no fear of mechanisation as a threat to his security. He sees in increased mechanisation the prospect of greater prosperity for his firm and indirectly for himself. He is a believer in the profit motive and has no objection to helping his employer to make more money so long as his own wage packet increases at the same time.

On the technical side, the Team found comparatively little that was not known and practised by the larger and more progressive concerns in the U.K. It is noteworthy that the organic surface coatings in common use in the industrial field in the U.S. are the

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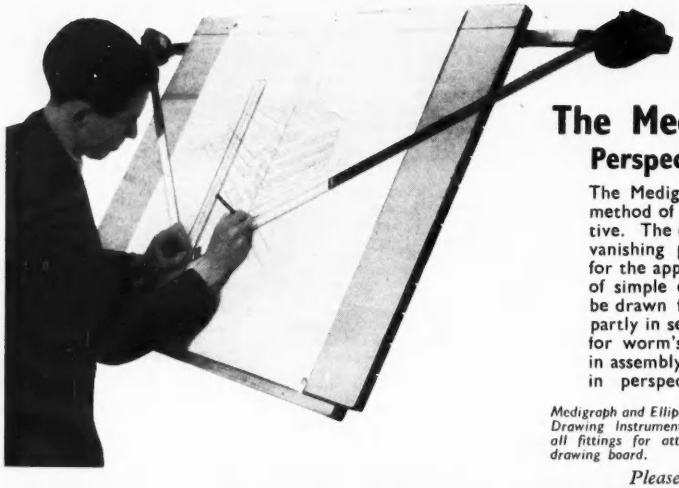

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same as in this country. In both plating and painting, the general standard of technical development, particularly in respect of the use by smaller concerns of new processes and ideas, appeared to be higher in the U.S. This is particularly true in respect of mechanisation. Whilst it is recognised that conditions are more favourable to intensive mechanisation in the U.S. and that indiscriminate mechanisation should be avoided, the Team recommends that "more attention should be given to the possibility of mechanising metal finishing operations in this country." To overcome the difficulty of short runs, which impedes the general adoption of mechanised methods over here, the possibility of greater specialisation should be considered.

The Report describes certain unusual features in the layout and utilisation of automatic and semi-automatic plating machines making for improved flexibility and economy of production and recommends that the layout of British plating shops should be reviewed to see whether the introduction of similar arrangements is practicable.

The difficulty and cost of producing electro-plated finishes is largely dependent upon the operations of polishing the basis metal, and American techniques in this matter are in general more highly developed than over here. In the first place, the surface quality of the basis metal available in the U.S.A. is considered by the Team to be generally superior to the average quality of the corresponding material in the U.K. This is particularly true of zinc-base die castings but was also noticeable on brass and on steel sheet. Thus, the initial problem is simplified for the Americans but, in spite of this, the reduction of polishing costs is a dominating feature of their metal-finishing practice. Direct methods include the greater use of automatic and semi-automatic polishing machines and the greater use of barrel polishing. Indirect methods include the use of copper undercoats (sometimes applied by the periodic reversal process); on unpolished or lightly-polished steel articles. This is done solely to take advantage of the greater ease with which copper may be polished as compared with steel. The more extensive use of bright and semi-bright plating processes, the use of electro-brightening and of pre-polished strip are further examples of the American approach to the polishing problem.

The automobile industry employs a so-called "kerb-side" finish for painted and plated components in which a satisfactory appearance from the normal viewing range (e.g., 6-12 ft. for an automobile) is accepted as the criterion. The high standards of finish based on close visual inspection called for in many British factories impose a considerable handicap on productivity and the Team recommends that, subject to maintaining the durability of the finish, the adoption of the American "kerb-side" standard should be given serious consideration.

The importance of metal cleaning and pre-treatment was clearly recognised. For paint finishes, most firms took great trouble to ensure that the model surface was chemically clean and, while no revolutionary methods for removing grease and dirt were seen, the widespread use of spray cleaners was noteworthy. There was also

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a clear appreciation of the need for careful control of phosphating solutions and every effort was made to render the operation as foolproof as possible. In the preparation of metals for electro-plating, too, the thoroughness of the American cleaning and rinsing cycles was striking.

The cost of application and, more important, the protective value of a finish, whether of paint or electro-plate, depends to a considerable extent upon the design of the article which is to be finished. "A much closer collaboration between design and finishing departments should be maintained so that the view of the finishing department on the practicability of a proposed design can be ascertained at the earliest possible moment."

Copies of the Report are obtainable from the Anglo-American Council of Productivity, 21, Tothill Street, London, S.W.1, price 3s. 6d. (post free).

TITANIUM MAY BE AIRCRAFT METAL OF THE FUTURE

Aircraft designers may have cause to remember with gratitude an English clergyman named William Gregor who in 1789 unearthed a new material—titanium. Although titanium is the fourth most common metal in the earth's crust, the main use for it in the past has been as a pigment in white paint. Now it is being investigated as the "metal of the future" for aircraft and jet engines.

Engine manufacturers are testing out small amounts of pure titanium in various parts of jet engines, particularly in the compressor blades, and it has been suggested that it might replace aluminium alloys for aircraft structures and guided missiles.

Its advantages are its light weight and strength and the fact that it does not rust and resists the inroads of acids and salt-water. It is only half the weight of steel, but with two or three times the strength of some aluminium alloys. But tests with pure titanium have shown that extravagant claims for it as a "wonder-metal" are not borne out: it is essentially a medium temperature material, not high temperature, and it is liable to what scientists call "creep." It is unlikely to be used for turbine blades, and intensive work will have to be done on alloys before it can be widely used.

But enough work has been done to spotlight the need for finding new supplies and bringing down prices. At present titanium is rare and expensive—the cost to Britain is about £5 a pound. And because it is scarce there has been a tendency to make do with other materials rather than rely on outside sources.

Like all materials, the cost is directly related to consumption. More speedy development for the Aircraft Industry may result from the welcome announcement, early in December, that the world's largest known deposit of titanium has been found in Australia, on the beaches and dunes of New South Wales and Queensland.

For the future, the high temperatures generated in guided missiles, mainly caused by skin-friction at supersonic speeds, calls for a new metal. Conventional materials will be inadequate for some of the supersonic types envisaged—even the war-time German V1 became red-hot at top-speed. But much more work on the production of titanium is necessary before sheet titanium, suitable for fuselages, becomes obtainable.

Other conventional aircraft parts may also be made of titanium, if the price comes down and the right alloys are developed, including propeller and undercarriages.

BOOKS

New Services' Standard for Proof Stress Testing. A new specification governing the determination of proof stress of metallic materials where this is called for in Government contracts has been published by the Ministry of Defence. It is one of a new series of general specifications for Inter-Services equipment drawn up by the Ministry's Engineering Standards Co-ordinating Committee.

Seven methods of testing are listed in the specification for use in Government orders unless individual notice is given that one or more of them are unsuitable. The specification also lays down the degree of accuracy which testing equipment should attain.

Copies of the specification (DEF 2—Proof Stress Testing) are obtainable from H.M. Stationery Office, price one shilling.

Modern Gas Turbines. With special Reference to Stationary, Aircraft, Locomotive and Marine Types, and to the Supercharging of Internal Combustion Engines. Second Edition, Revised. By Arthur W. Judge. 388 pp., 248 illustrations. Publishers: Chapman & Hall Ltd., 37 Essex Street, London, W.C.2. PRICE: 32/- net.

Classified Advertisements.

The rate for all classified advertisements is 6d. per word; in bold print 9d. per word; minimum order 6s. Box number advertisements 1s. extra. Instructions together with remittance must be received not later than the 3rd of each month for advertisements to appear in the same month's issue.

SITUATIONS VACANT

ADMIRALTY. Applications are invited for Architectural and Civil Engineering Assistants for temporary service in the Works Department at most Admiralty establishments in the United Kingdom. Opportunities will arise for service at Admiralty Dockyards abroad. Candidates must be British subjects who are competent draughtsmen and designers with experience in the following types of Building and Civil Engineering Works: Structural Steelwork, Reinforced Concrete, Dock and Harbour Works, Accommodation, Residential, Offices, Store and Factory Buildings, Oil Fuel Tanks and Pipe Lines, Airfield Construction and Maintenance, Rail, Road, Water Sewerage and Heating Services, etc. Salary will be assessed according to age, qualifications and experience up to a maximum of £675 p.a. Additional allowances are payable for service abroad. Applications giving age, details of qualifications, training and experience should be forwarded to the Civil Engineer-in-Chief, Admiralty, Chamberlain Way, Pinner, Middlesex Interviews will be arranged at Admiralty Establishments convenient to the candidate's address.

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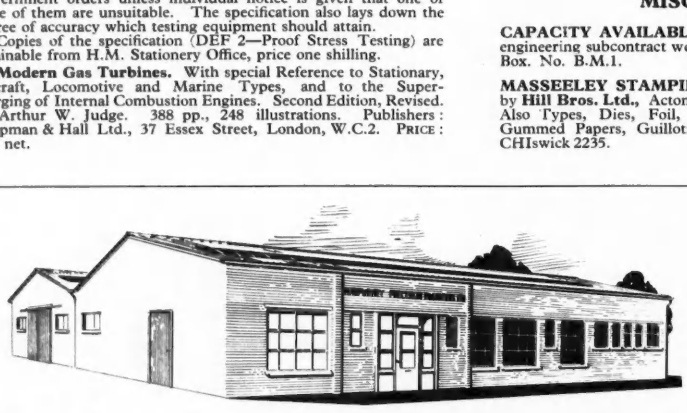

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Magnetic Moulding Machines

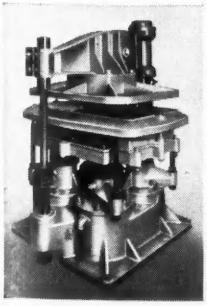
Operation and Applications

In foundries laid out for large scale repetition work moulding machines long ago proved their worth; today the advantages afforded by the Magnetic type of moulding machine are helping towards even greater efficiency and economy. These machines whilst frequently having a somewhat higher initial cost than other types of mechanical moulding machines gain by their low installation charge, negligible maintenance and the immense saving in running costs amounting to as much as £85 in twelve months.

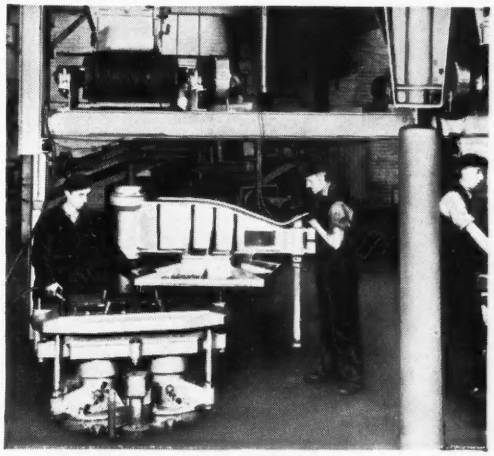
Moulding pressure in the magnetic types is applied through a D.C. solenoid. Apart from the cable connecting the machine to the power supply, there are no other connections, pipes or any exterior equipment, although a D.C. supply is of course essential. It is, in this respect, virtually self-contained, and, since there are few moving parts, requires very little maintenance.

Operation

No technical knowledge is required by the operator, for the machines are automatically controlled by a simple push-button system that is practically foolproof. When the push-button is released at the end of the pressure stroke the pattern is automatically stripped from the mould, the stripping speed being controlled by the rate of displacement of oil in the main dashpot. Electric vibrators are normally fitted which are energised momentarily immediately the "squeeze" push-button is released, to ensure that the pattern is stripped cleanly from the mould. Electric heaters (with 3-heat control switch) can be supplied to prevent the moulding sand from adhering to the pattern. The machines can usually be arranged to suit equipment already standardized for machine moulding methods. But it is, perhaps, on the evidence of power consumption-figures that the case for magnetic moulders presents its strongest argument. Unlike hydraulic or pneumatic machines where compression power must be maintained at all times throughout the shift, magnetic moulding machines only use electric power during the time the actual moulding stroke is being made—for perhaps 1½ to 2 seconds. A typical example is quoted of a magnetic moulding machine producing 350 complete moulds in boxes 20″ x 12″ x 3½″ deep, for an electrical consumption of approximately 3½ units; a remarkable figure by any comparison. When a battery of machines is in use, the electrical control includes a sequence selector device to prevent the solenoids of two or more machines being energised simultaneously, thus automatically limiting the instantaneous power demand.



Down-sand frame magnetic moulding machine.



Magnetic moulding machine producing moulds for heavy cooker-frame castings

Types of Machine and Applications

The two most popular types in current use are the "Squeeze-strip" and "Down-sand Frame squeeze strip" machines. The former has a very wide and diverse application; the latter is particularly applicable to the production of moulds for flat or shallow castings where the box depth does not exceed 6 inches.

"Double-face Boxless" and "Roll-over" types are also manufactured to meet special requirements. Slight differences in the types of machine available enable manufacturers to choose a model most suited to their particular requirements.

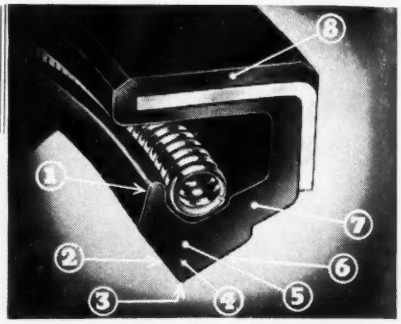
The field of application is wide and includes the production of moulds for the components of gas, electric and solid fuel combustion cookers and stoves; industrial and agricultural machine parts, electrical fittings and instrument components.

Magnetic Moulding Machines are made exclusively by British Insulated Callender's Cables Limited in their Prescot factory; this organization also provide the customary "After Sales Service".

For those who wish to know more about the application of Magnetic Moulding Machines in the foundry, BICC have published detailed information (Publication 276U) which is available on request to:

BI Callender's

British Insulated Callender's Cables Limited
Norfolk House, Norfolk Street, London, W.C.2



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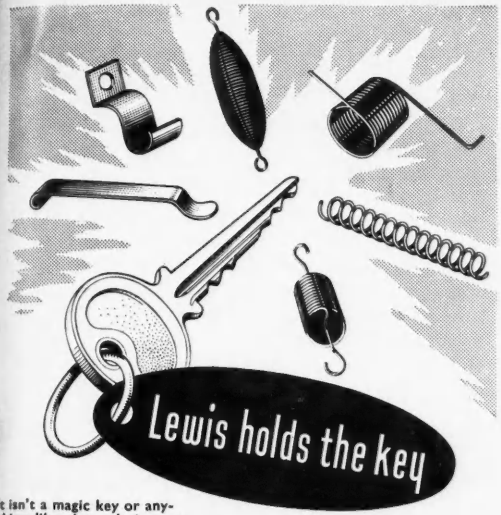

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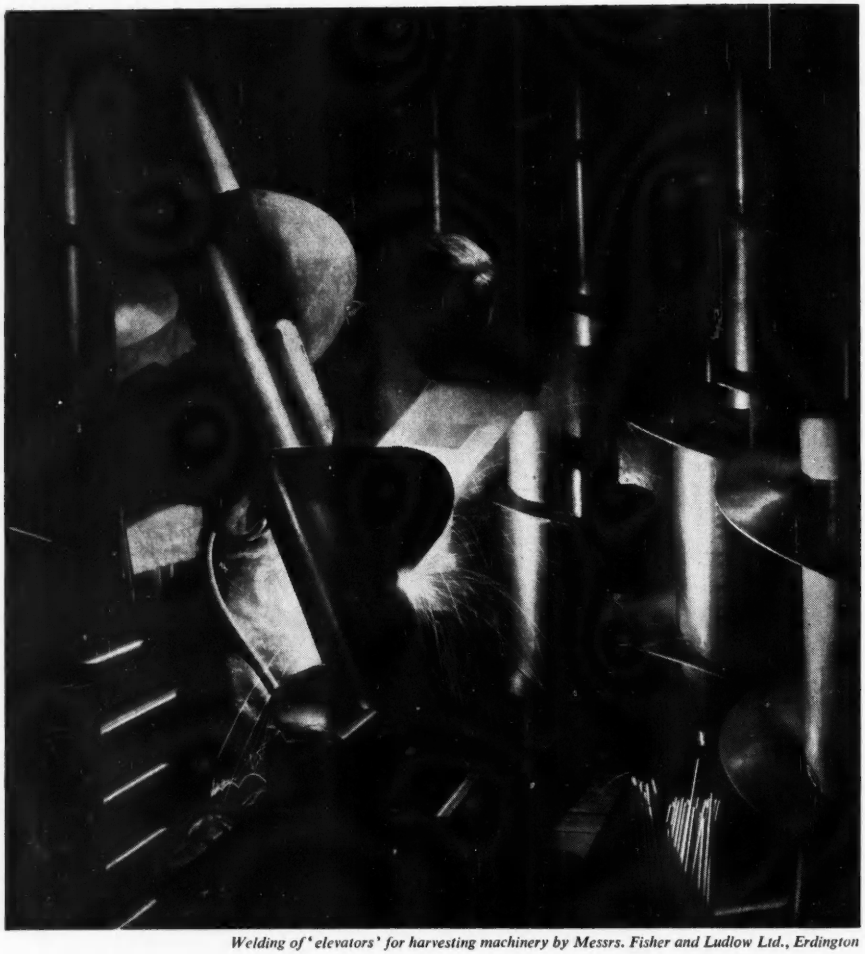

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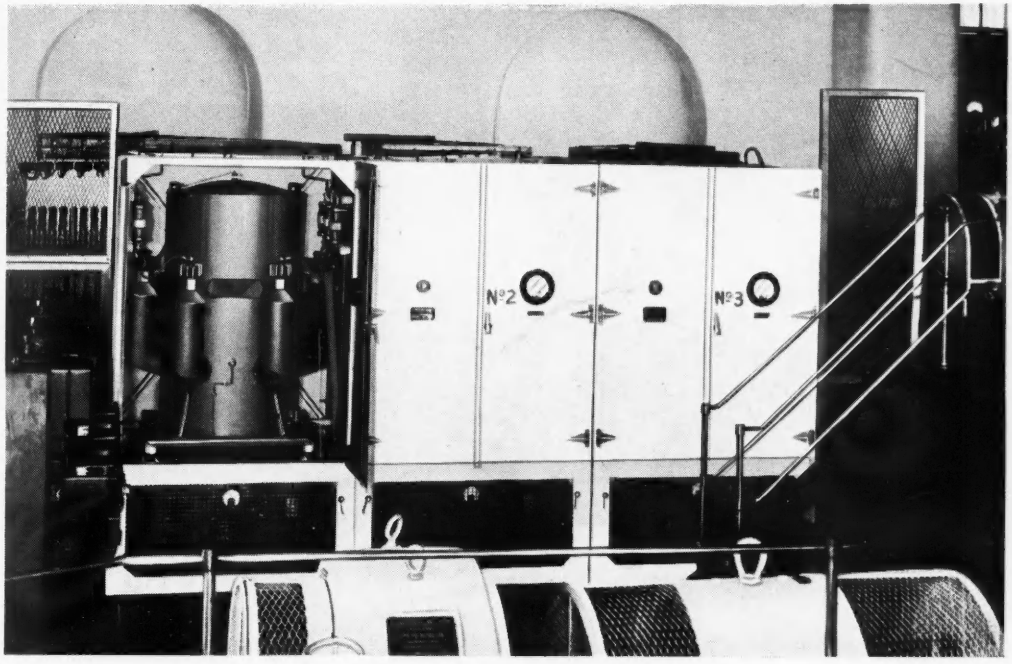

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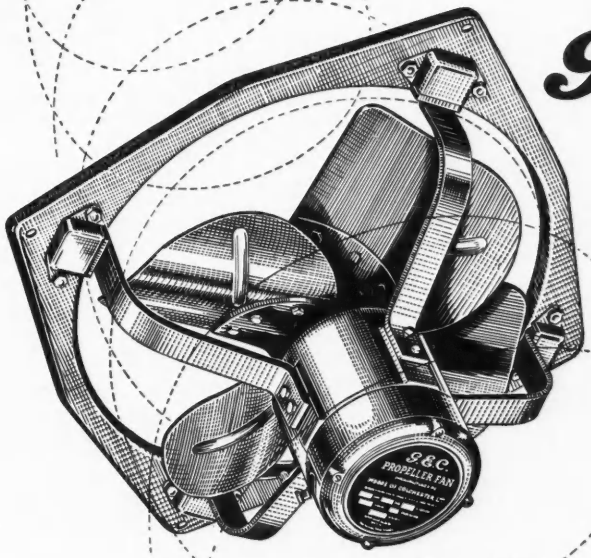

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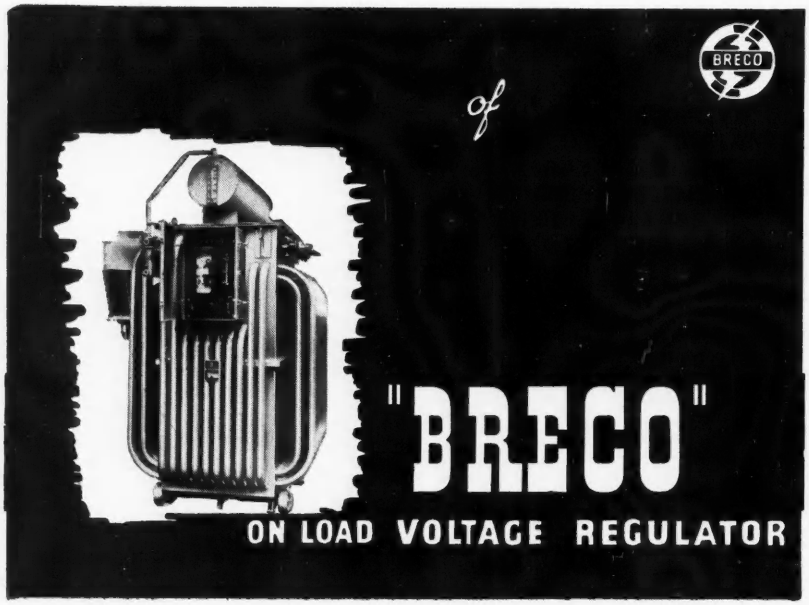

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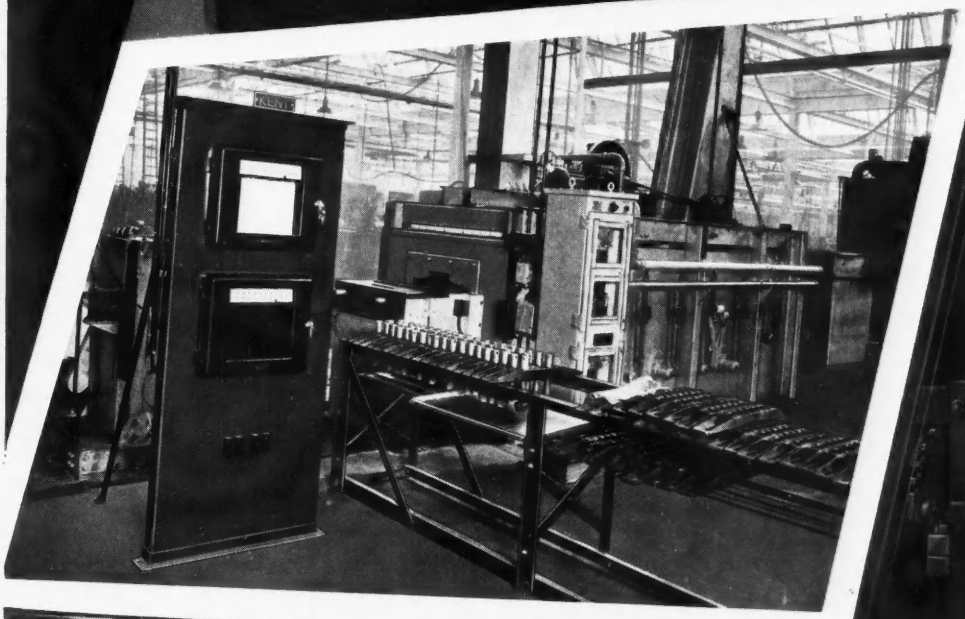

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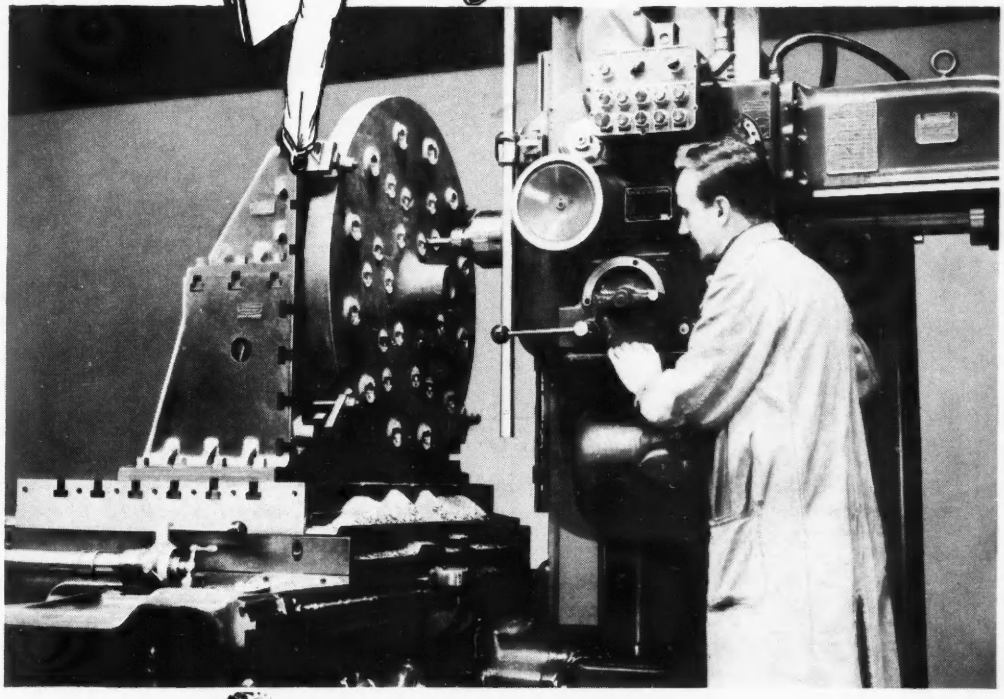

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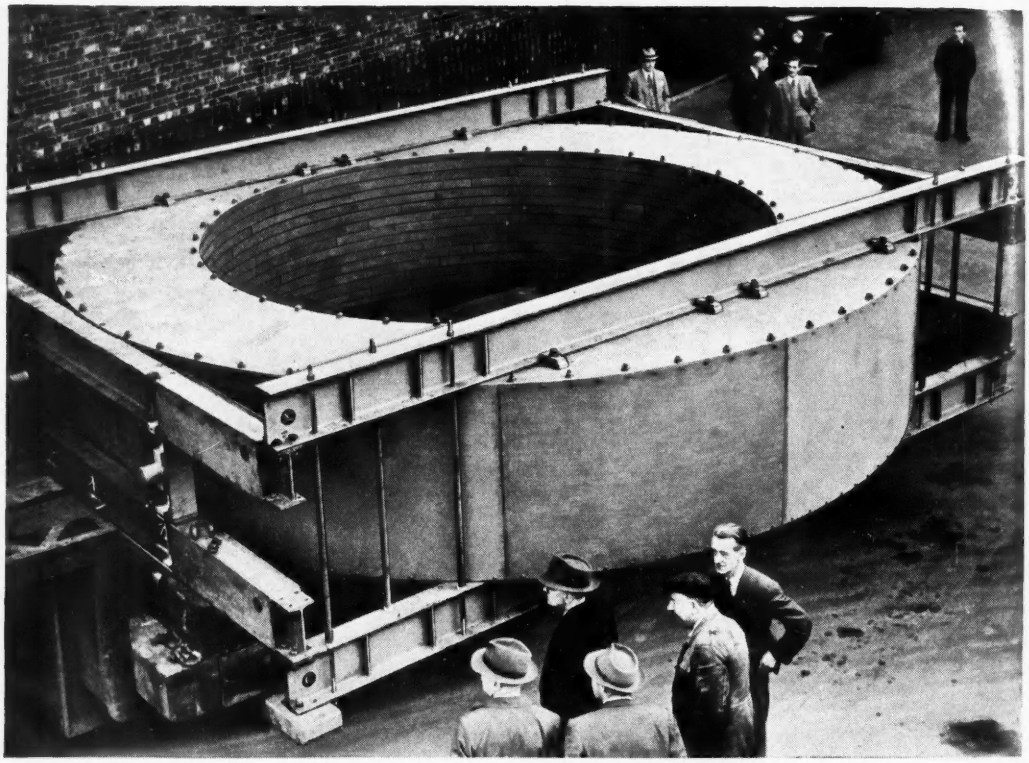

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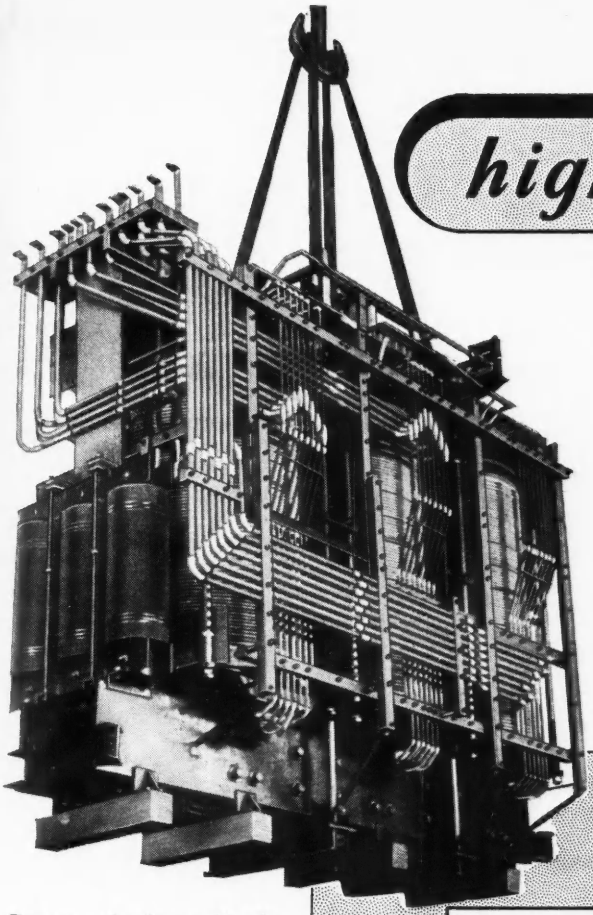

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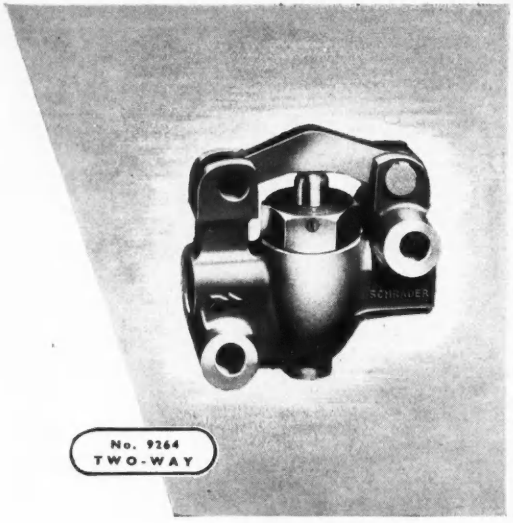

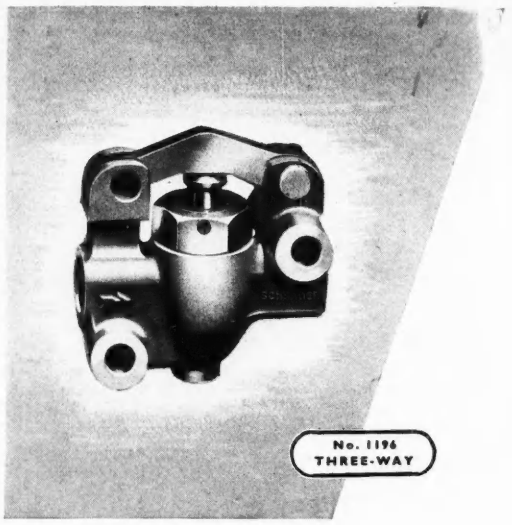

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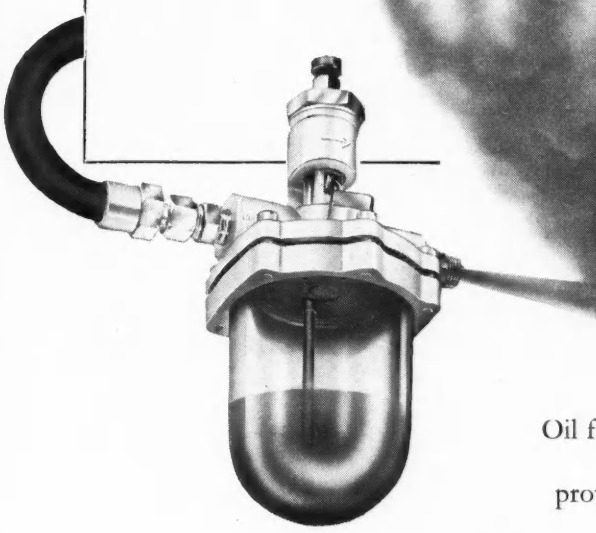

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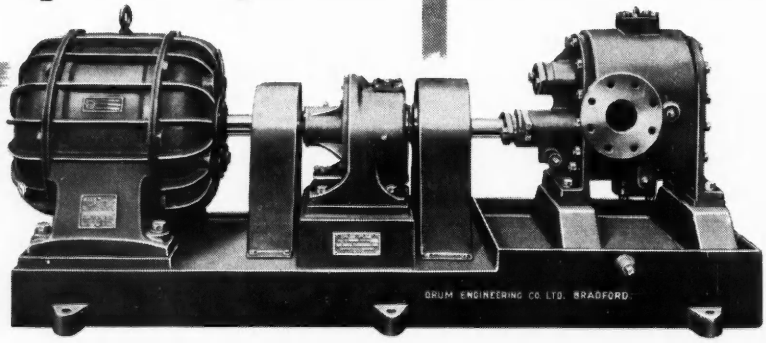

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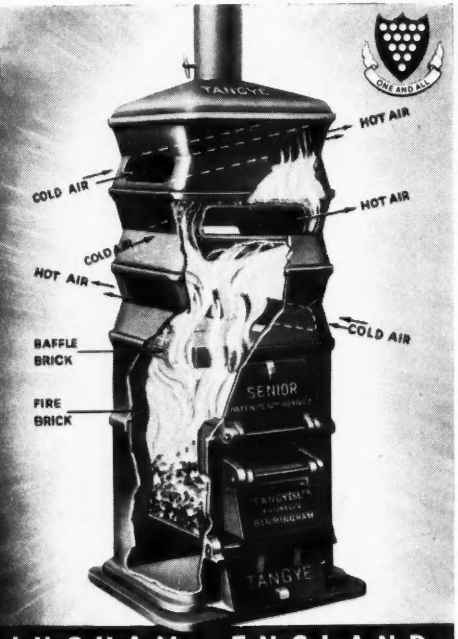

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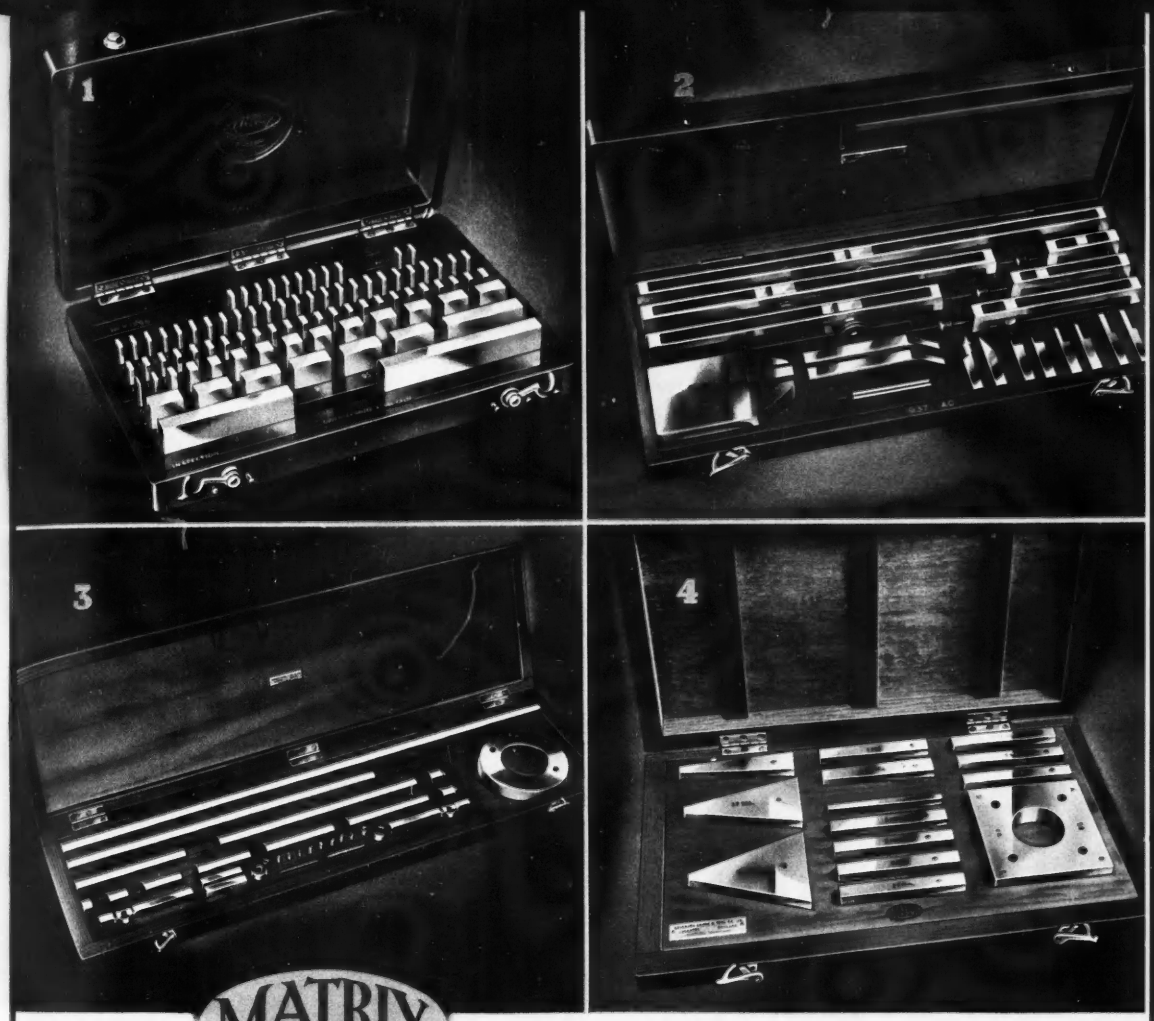

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3 " Matrix " Length Bars for precise measurement of distances beyond the limits of ordinary gauges.

4 " Matrix " Angle Gauges for combination use to check any angle from 0 to 360 deg.

Coventry Gauge & TOOL CO. LTD. COVENTRY OF BRITAIN

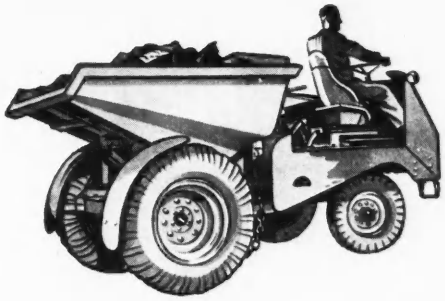
Are you on the right line?

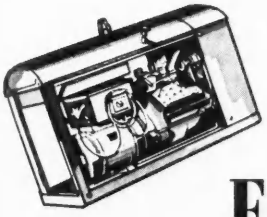
You can't go wrong if you call in "G.W.B." when you need LARGE Electric Furnaces. Because of our association with Gibbons Bros. and Wild-Barfield, some people "get these lines crossed"; G.W.B. are a complete and separate unit and have all the resources and experience to supply Large-Scale industrial heat-treatment equipment. Make no mistake about it when you next require LARGE Electric Furnaces, get on the right line—get on to G.W.B.

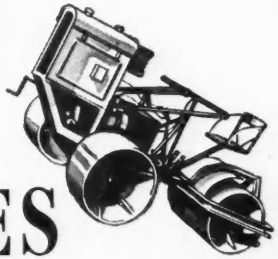
For *LARGE* Electric Furnaces it's WB

G.W.B. ELECTRIC FURNACES LTD., DUDLEY, WORCS. *Phone: Dudley 4284/5*

Proprietors: GIBBONS BROS. LTD. and WILD-BARFIELD ELECTRIC FURNACES LTD.



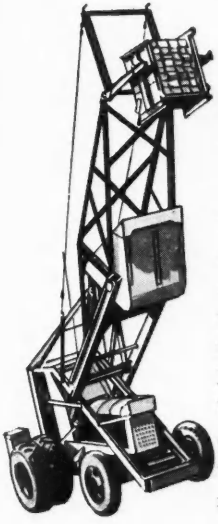




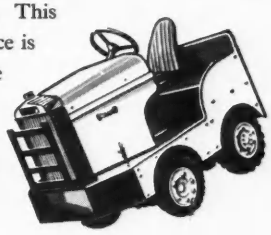
FORD ENGINES

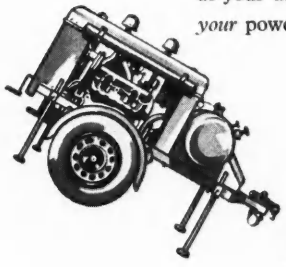
for

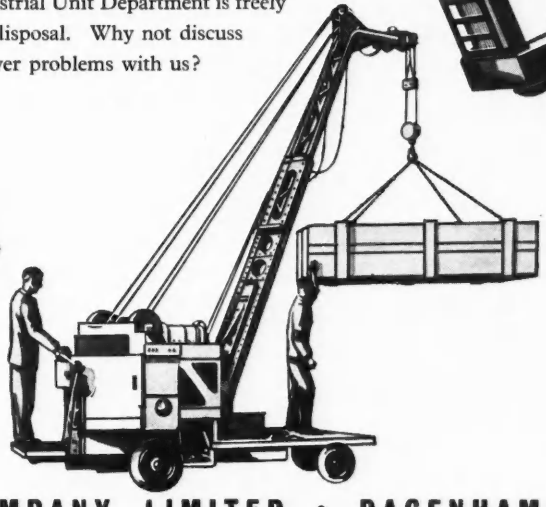
INDUSTRIAL EQUIPMENT



Ford Industrial engines are widely used in providing power for Industrial Machinery of every description and have a power range between 10 and 60 B.H.P. when required for continuous working purposes. They are inexpensive to buy and economical to run. They give you long and trouble-free service, and what little maintenance they need is promptly and speedily carried out by Ford Service, which covers every part of the country. This combination of a first-class product and first-class service is the reason why Ford engines hold an unchallengeable reputation in every branch of industry. The advice of our Industrial Unit Department is freely at your disposal. Why not discuss *your* power problems with us?

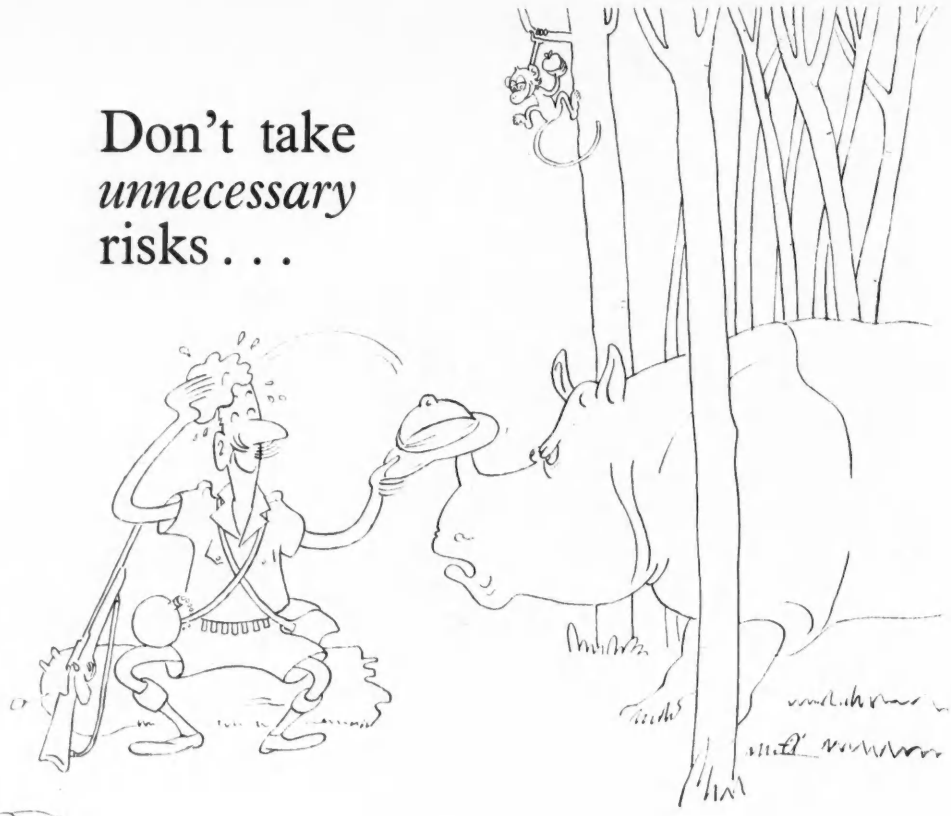






FORD MOTOR COMPANY LIMITED • DAGENHAM • ESSEX

Don't take *unnecessary* risks . . .



WHEN this overheated hunter gets his topee back he'll think twice before he takes another unnecessary risk. Yet taking needless risks is the easiest thing in the world — every day someone or other somewhere or other is suffering through hanging his hat on the wrong peg. No use being wise *after* the event . . . the fact is whether you're a Big Game Man or a Big Business Man you just can't afford unnecessary risks — it pays to be sure in the first place!

WARNING TO MANUFACTURERS : You take unnecessary risks whenever you buy 'cheap' springs of uncertain quality; low initial outlay will never balance the ultimate harm they may do to your product, your prestige and your purse. When you specify "Springs by Salter" you're certain of getting top-flight quality — quality that cuts out risks and guarantees years of highly-efficient, dependable service. Only the best — of materials and workmanship — is good enough for SALTER.

INSIST ON QUALITY

Buy **SALTER** *of course*

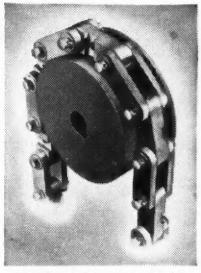
Est. 1760

GEO. SALTER & CO. LTD., WEST BROMWICH

Artillery...

FOR BRIGHT SPARKS

Positively 'bang-on', this use of Tufnol to form the handle and guard of an electrode holder — although high electrical insulating properties are by no means the only shots in the locker of this very versatile material. Its uses are legion arising out of its sympathetic working with metals in the form of bearings, pulleys, and gears — its resistance to moisture and corrosion — its low specific gravity combined with good structural strength. For the most part, Tufnol is simply bought in the standard forms of sheets, tubes, rods, bars, angles, channels, and other sections, to be machined as one would metal or hardwood. But it can also be supplied in specially moulded shapes or as finished machined components. Even those who have used Tufnol from the beginning, still find its possibilities endless.



Tufnol chain and jockey pulley for use in a de-scaling plant where they work in a boiling acidulated solution. The chain withstands a pull of 480 lbs.

CAN TUFNOL HELP YOU?

Informative literature is available giving full information on Tufnol. Furthermore, our enthusiastic Technical Staff welcome any new problems involving the possible use of this versatile material. An indication of your requirements in a letter, will bring a prompt and helpful reply.

TUFNOL

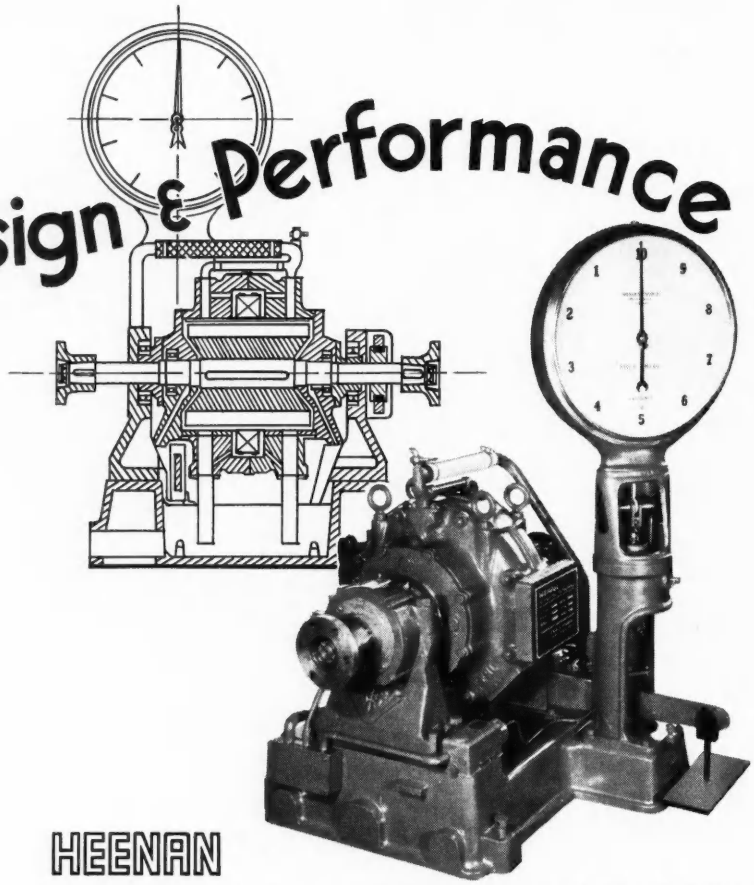
REGISTERED TRADE MARK

An ELLISON Product

TUFNOL LTD • PERRY BARR • BIRMINGHAM • 22B

245

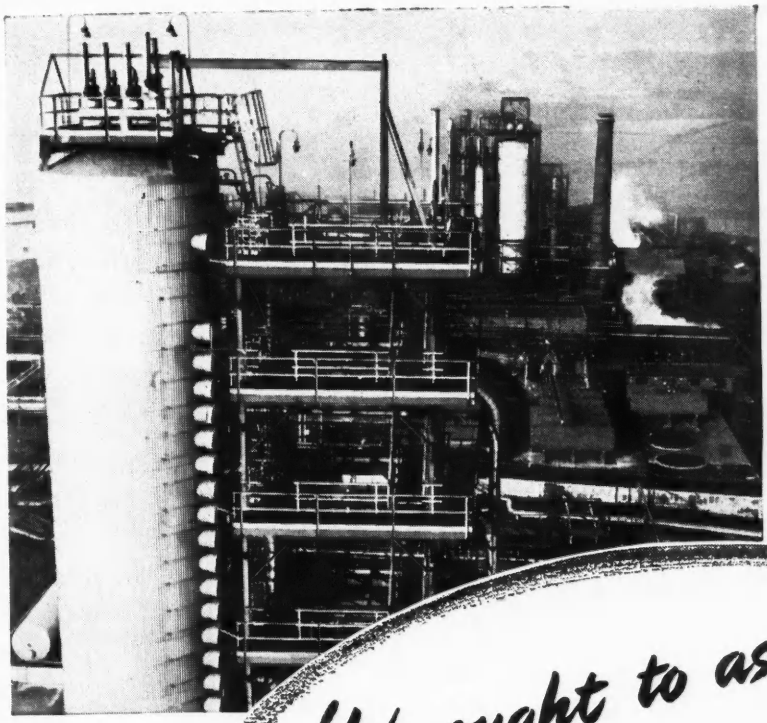
Design & Performance



HEENAN
DYNAMATIC DYNAMOMETERS

- These Dynamometers are in widespread use for testing all kinds of prime movers. They operate upon the Eddy-Current principle.
- The rotor is surrounded by a stationary electro-magnetic coil the excitation of which creates the desired resistance to rotation.
- Electronic control is normally employed, providing very desirable torque-speed characteristics. The control panel can be set at any desired distance from the Dynamometer.
- Special high-speed models are available for testing such prime movers as gas-turbines.

HEENAN & FROUDE LIMITED WORCESTER ENGLAND



Benches A and B Distillation Plant of the National Oil Refineries Limited at Llandarcy, South Wales, where the throughput is 80,000 barrels per day. Lincoln arc-welding again, of course.

'We ought to ask Lincoln before we decide'

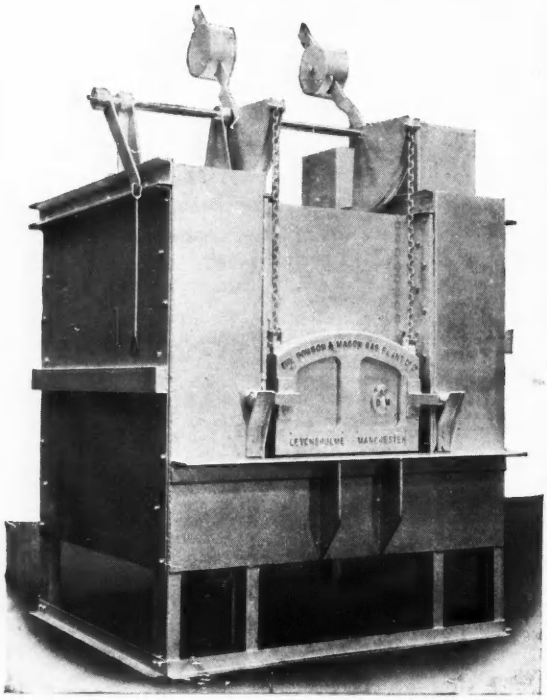
LINCOLN

World's largest manufacturers of arc-welding equipment and electrodes

LINCOLN ELECTRIC CO LTD · WELWYN GARDEN CITY · HERTS · WELWYN GARDEN 920

SM26

oil fired forging furnace



Door Opening 2′ 0″ wide by 1′ 3″ high. Working Hearth 3′ 6″ wide by 2′ 9″ long (3′ 6″ from door face to back wall.

The
DOWSON & MASON
GAS PLANT COMPANY LTD
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SUCCESSFUL FLUID HANDLING...

pre-supposes successful fluid sealing. Flexibox Mechanical Seals are indispensable for successfully sealing the shafts of centrifugal and rotary pumps, agitators and mixers, gas compressors and vacuum pumps, and refrigeration compressors. Today Flexibox Mechanical Seals are used in oil refineries, chemical works, food factories, power stations, cold stores, refrigerators, aeroplanes, ships and motor cars, all over the world. Just why have Flexibox Mechanical Seals proved so successful? Because superior design, selected materials, precision workmanship and unrivalled test facilities all combine to make seals of the highest efficiency—seals which are compact, reliable and easy to install.

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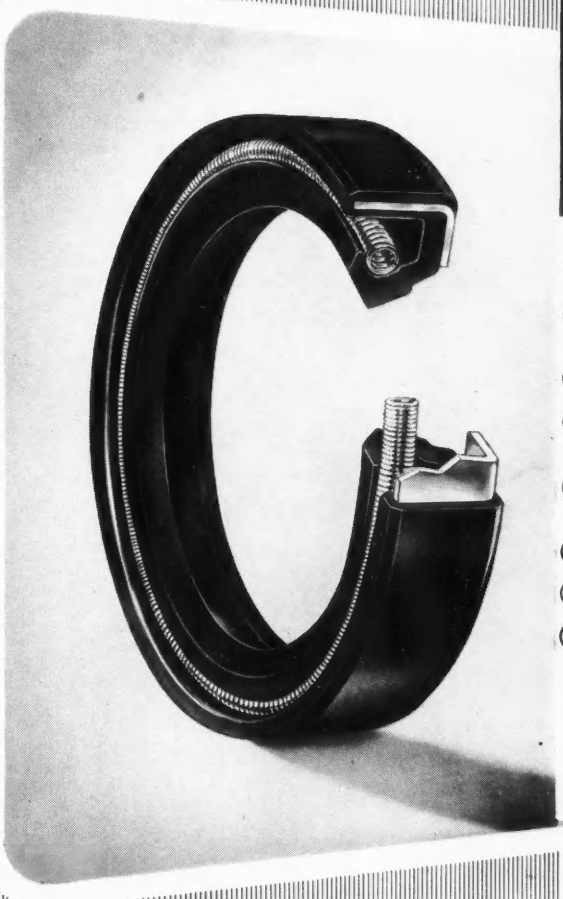
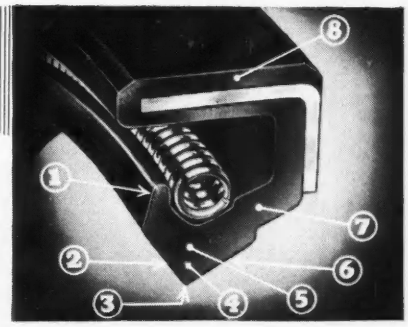
A MEMBER OF THE M·O·R GROUP OF COMPANIES





1. Deep rim affords perfect Spring Retention.
2. Large Face Angle brings Sealing Edge well below spring.
3. Knife Edge Contact at Sealing Point.
4. Sealing Point stiffened against local deformation by large included angle.
5. This section stiffened to prevent deformation under load.
6. Shaft angle gives adequate clearance.
7. Flexible Web.
8. Gaco Skin affords better fluid tight fit in housing.

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THE

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The Scientifically Designed Oil Seal which is now the accepted standard for Rotary Shaft Oil Retention. Made of GACO!

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Fluid Sealing Engineers

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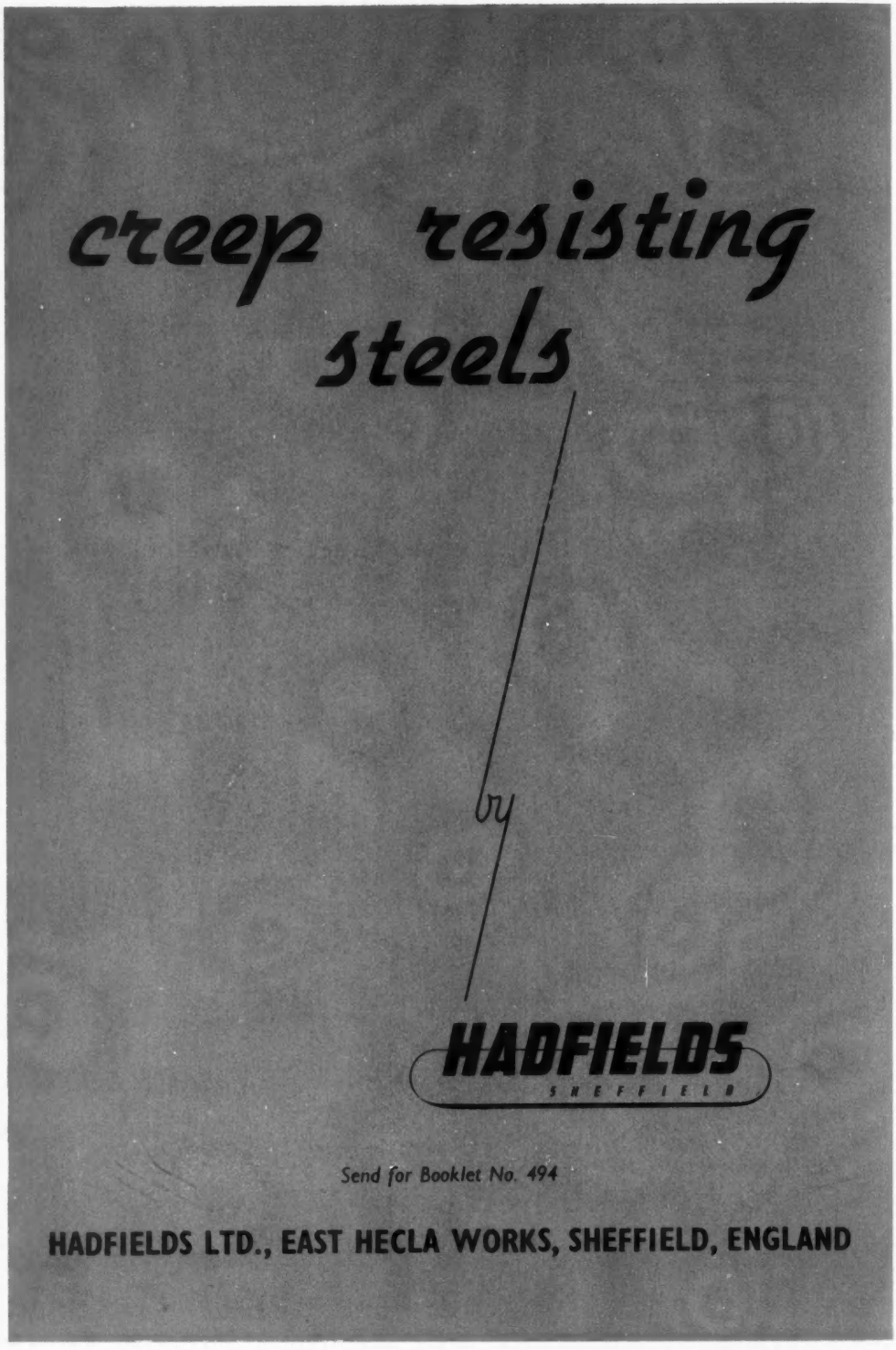
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An Announcement. .

DUREX ABRASIVES LTD wish to announce that as from June 14th, 1951, the name of the Company has been changed and is now the MINNESOTA MINING & MANUFACTURING COMPANY LTD. The range will in future bear the name of the new Brand-titles listed below, and the kind co-operation of the Trade in the use of the new brand names would be appreciated in future ordering.

Existing high standards in the quality of the products will be maintained, the change is in name only.

CHANGE OF NAME

"Durexite" Cloth	to	**"Three-M-ite" Cloth**
"Durexite" Cloth Economy Rolls and Sheets	to	**"Three-M-ite" Cloth Elek-tro-cut**
"Hydro-Durexite" Cloth	to	**"Wetordry Three-M-ite" Cloth**
"Durexite" Fibre Combination Discs	to	**3M Discs Type A**
"Durexite" Resin Bond Discs	to	**3M Discs Type C**
"Durexsil" Fibre Combination Discs	to	**"Tri-M-ite" Fibre Combination Discs**
"Hydro-Durexsil" Cloth	to	**"Wetordry Tri-M-ite" Cloth**
"Hydro-Durexsil" Paper	to	**"Wetordry Tri-M-ite" Paper**
"Durexsil" Paper	to	**"Tri-M-ite" Paper**
"Durexsil" Cloth	to	**"Tri-M-ite" Cloth**
"Durexalo" Paper	to	**3M Production Paper**

Distributive Arrangements unchanged. Supplies obtainable from former Durex Brand Distributors

CHARLES CHURCHILL & CO. LTD.
Birmingham and Branches.

BURTON GRIFFITHS & CO. LTD.
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R. W. GREEFF & CO. LTD.
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3M COMPANY

and from the Manufacturers

MINNESOTA MINING & MANUFACTURING COMPANY LTD.
ARDEN ROAD · ADDERLEY PARK · BIRMINGHAM 8.

When you need a material
stronger than wood
lighter than metal
. . then you need

PERMALI

Laminated · Densified · Impregnated

Sample shows impregnated veneers before and after compression

Write for Data Book N.93 which shows recent engineering applications.

PERMALI LIMITED

GLOUCESTER, ENGLAND

Telephone : 24941. Telegrams : 'NICO' Gloucester

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UNUSUAL PROBLEMS SOLVED WITH **Bostik**

CASE 3

OLD KING COAL must keep moving!

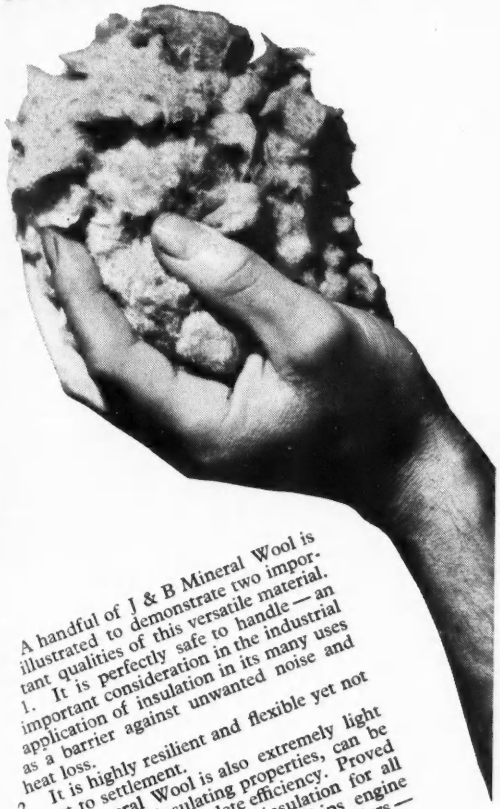
ONCE COAL IS CUT it must be conveyed. In fact, next to coal-cutting, coal-conveying is the most important part in the vital work of wresting black diamonds from Mother Earth. The conditions under which conveyor-belts operate are very severe indeed. Cuts occur in belt after belt. A Bostik Sealing Compound impervious to water has been produced for the purpose of repairing these cuts. It wouldn't strike the average person that an industrial Sealing Compound could play such an important part in coal mining. And perhaps it hadn't occurred to you, until now, that Bostik products of one grade or another might be the solution to an industrial sealing or adhesive problem of your own. Brief details to B. B. Chemical Co. Ltd., Ulverscroft Rd., Leicester, could be the turning point.

There might well be a use for

Bostik

Industrial Adhesives and Sealing Compounds in **YOUR Business**

SAFE to handle



A handful of J & B Mineral Wool is illustrated to demonstrate two important qualities of this versatile material.
1. It is perfectly safe to handle — an important consideration in the industrial application of insulation in its many uses as a barrier against unwanted noise and heat loss.
2. It is highly resilient and flexible yet not subject to settlement.
J & B Mineral Wool is also extremely light and, due to high insulating properties, can be used sparingly with complete efficiency. Proved by test the ideal medium of insulation for all purposes such as Industrial and Ships engine equipment — Furnaces and Ovens — Boilers — Refrigeration Machinery, etc.

J&B

MINERAL WOOL

The Perfect Insulant

FIREPROOF · NON-CORROSIVE · ANTI-VERMIN
WATER REPELLENT · PREFABRICATED IN MANY FORMS

Enquiries, please to advisory Dept. S. 12

JONES & BROADBENT LTD

Thermal & Acoustic Insulation Specialists

PERREN ST., LONDON, N.W.5

Phone : GULliver 2120, 5548/9.

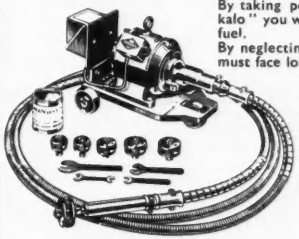
and at REDCAR, MANCHESTER, BRISTOL and BURTON-ON-TRENT.

We hold a warrant FOR THE arrest OF SCALE

FOR CAUSING OBSTRUCTION!

SKATOSKALO

"Skatoskalo" descaling equipment provides the most effective method of searching out and destroying SCALE.
By taking positive action with "Skatoskalo" you will save 10% to 15% of your fuel.
By neglecting this insidious menace you must face loss of efficiency, loss of profit during costly overhauls and capital loss due to the damage which Scale threatens to do throughout your plant. Send for our loose-leaf Catalogue E.D., and learn how "Skatoskalo" flexible drive apparatus achieves destruction of Scale without the dismantling which attends the use of less flexible descaling equipment.



Flexible Drives

(Gilmans) LTD.

INCORPORATING F. GILMAN (B.S.T.) LTD.

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'Grams: Skatoskalo, Phone, Birmingham

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195, HIGH STREET, SMETHWICK 41, STAFFS.

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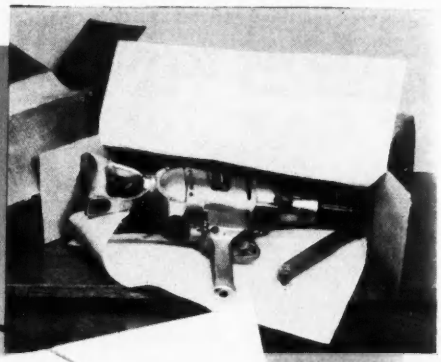

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PORTABLE ELECTRIC TOOLS
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TELEGRAMS & CABLES "BLACDECK" WEST DRAYTON

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OUR REF ADB/BMS.

DATE 27th August, 1951.

Messrs. Leonard Stace Limited,
York Place,
Swindon Road,
Cheltenham.

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We will have no hesitation in recommending your excellent V.P.I. papers and efficient service to any other potential user,

I remain,

Yours faithfully,
for BLACK & DECKER LIMITED.

A.D. Bishop.
Packaging Co-ordinator.

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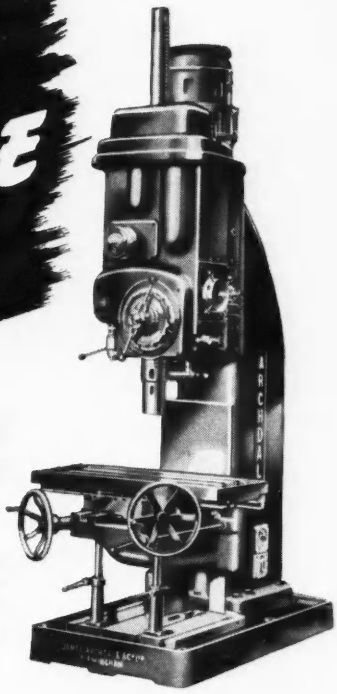
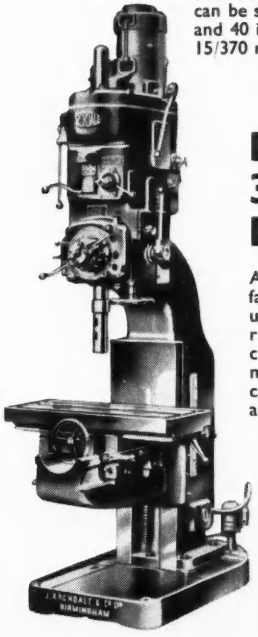


Drills up to 4" from solid 32" Heavy Duty Vertical Drilling Machine.

A powerful machine for drilling holes from the solid in mild steel, up to 4 in. dia. Will tap up to 3 in. in cast iron. Plain or compound table (as illustrated) can be supplied, with working surface 24 in by 22 in. and 40 in. by 14 in. respectively. 12 spindle speeds, 15/370 r.p.m. and 6 feeds 30/240 r.p.i.



Drills up to 3" from solid 30" Heavy Duty Vertical Drilling Machine.

A heavy duty machine, easy to operate and capable of fast drilling rates on a wide variety of work. Will tap up to 2 in. Whit. 17 spindle speeds from 15 to 1500 r.p.m. or, if preferred, twelve speeds selected from choice of four alternative ranges. There are six automatic feeds, 30 to 240 r.p.i. Plain or compound tables can be supplied, with working surface 16 in. by 18 in. and 16 in. by 34 in.

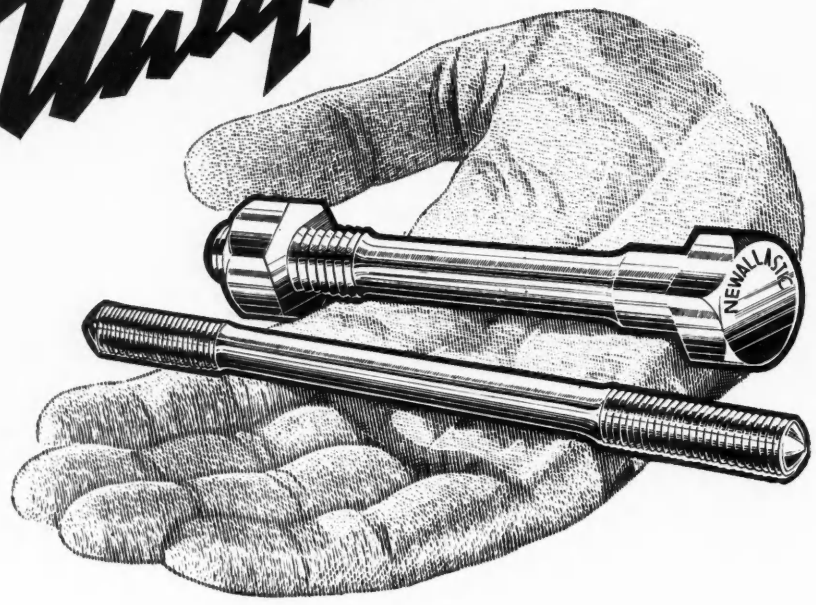
ARCHDALE

HEAVY DUTY VERTICAL DRILLS

JAMES ARCHDALE & CO. LTD. BIRMINGHAM

Sole Agents: ALFRED HERBERT LTD. COVENTRY.

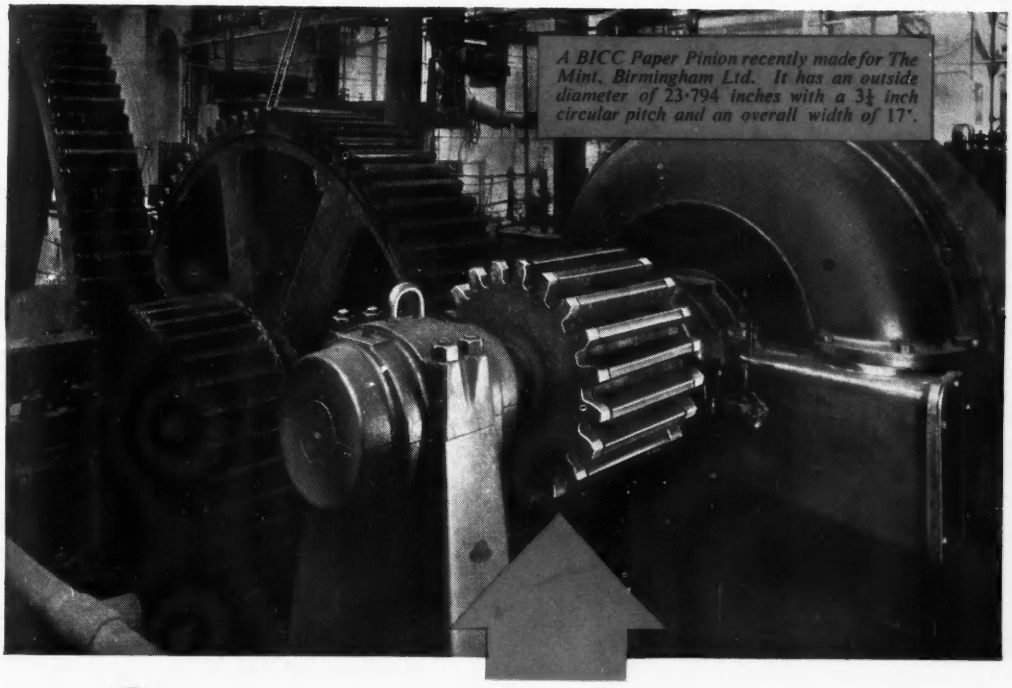
Unique



"Newallastic" bolts and studs have qualities which are absolutely unique. They have been tested by every known device, and have been proved to be stronger and more resistant to fatigue than bolts or studs made by the usual method.

C. P. Newall & Co., Ltd.

POSSILPARK GLASGOW · N



A BICC Paper Pinion recently made for The Mint, Birmingham Ltd. It has an outside diameter of 23·794 inches with a 3¼ inch circular pitch and an overall width of 17".

B.I. Callender's

PAPER PINIONS

for

LONG QUIET service

under heavy variable torque loading

BICC Paper Pinions run quietly and smoothly, and by absorbing the vibration in fast, high power transmission gears greatly reduce wear on the machine. They need little lubrication and are extremely durable. Indeed, some have been running for over 25 years and are still giving good service, the mating metal spur wheels being in excellent condition.

BICC Paper Pinions are unaffected by variations in temperature, and when specially prepared will work satisfactorily in the presence of oil and water. With BICC machine-cut spur gears they provide efficient and economic drives for many varied applications.

Pinions and spur gears are cut to customer's individual requirements.

Further information can be obtained from any BICC Branch or from our Head Office.

BRITISH INSULATED CALLENDER'S CABLES LIMITED
NORFOLK HOUSE, NORFOLK STREET, LONDON, W.C.2

"No. 4 still Overheating?"

"NO—we installed Tecalemit Lubrication while you were away"

OVERHEATING . . . slow down . . . stop ! That idle machine may lose you a lot of business, certainly money. And the cause is probably incorrect or faulty lubrication. Now that doesn't happen with Tecalemit Centralised Lubrication — fully automatic, semi-automatic or manually operated — because the correct amount of oil or grease is fed to every bearing at the correct intervals of time. This enables you to run machines FASTER with complete safety and so increase your production.

A Tecalemit Engineer will gladly call and give you all the information you require.

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The Authority on Lubrication
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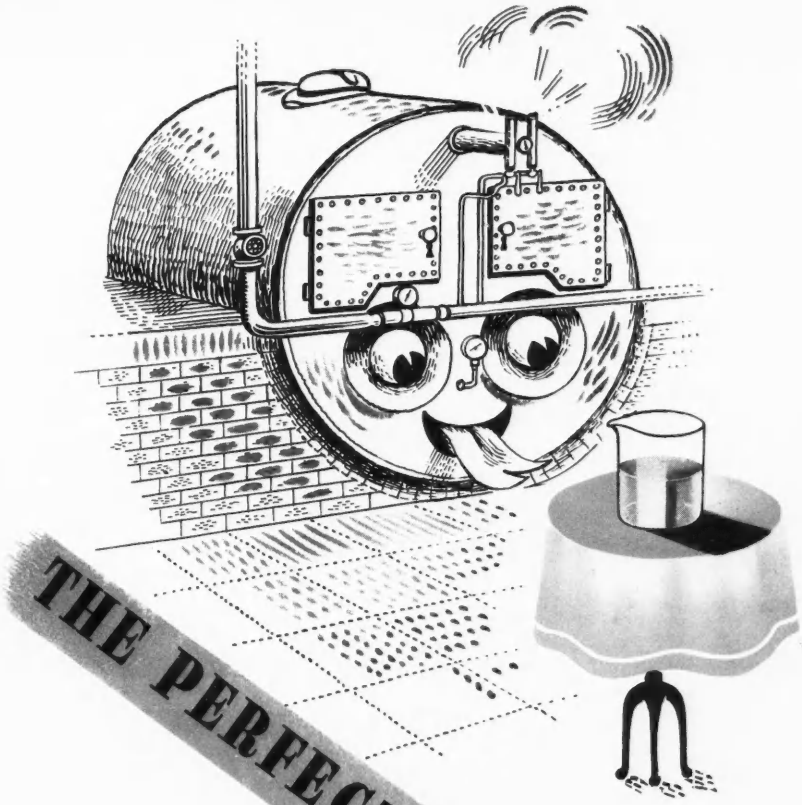

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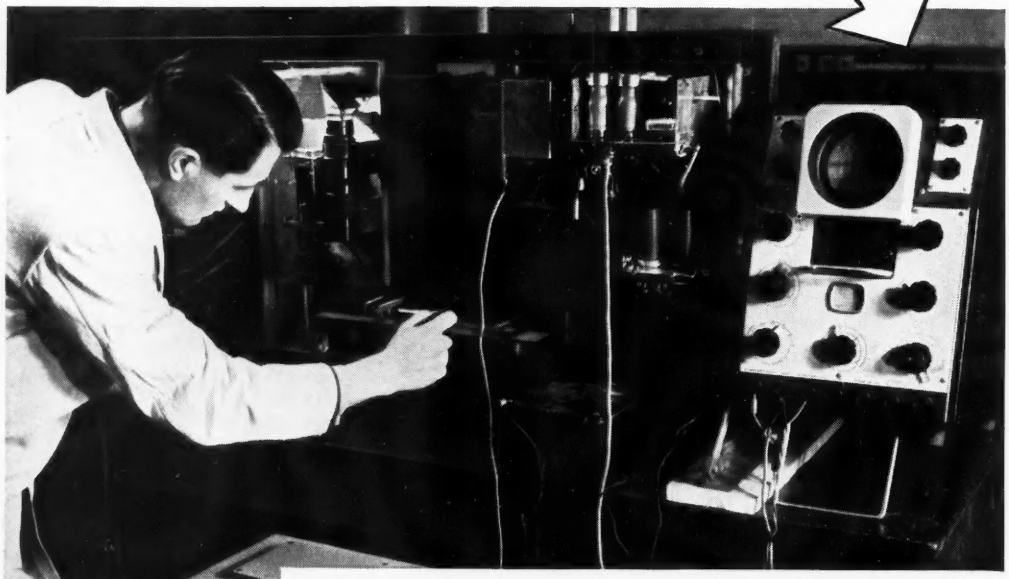

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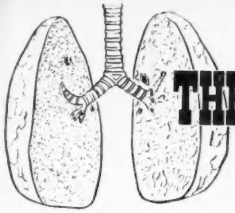

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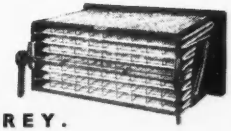

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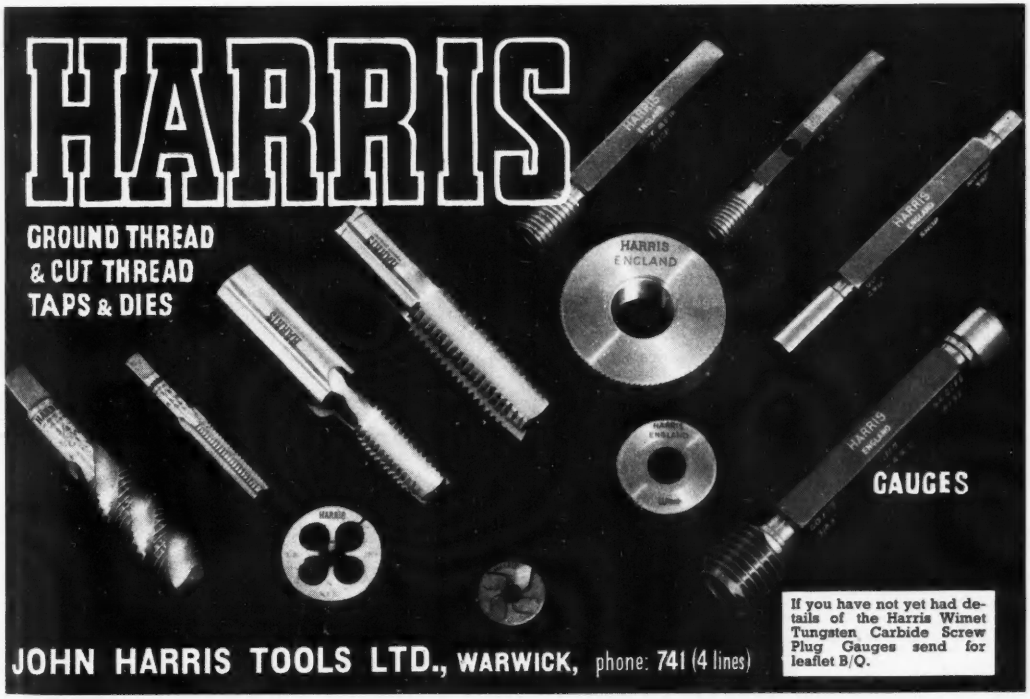

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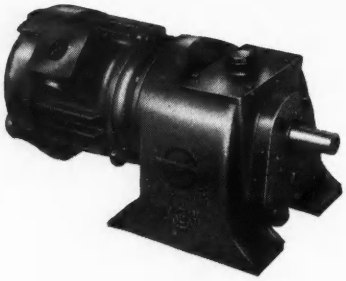

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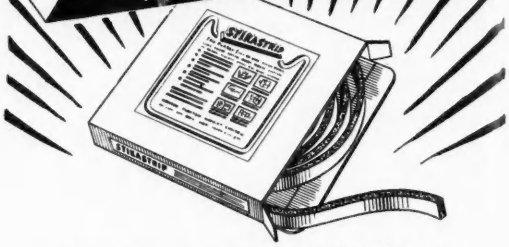

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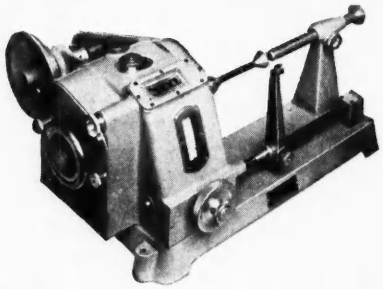

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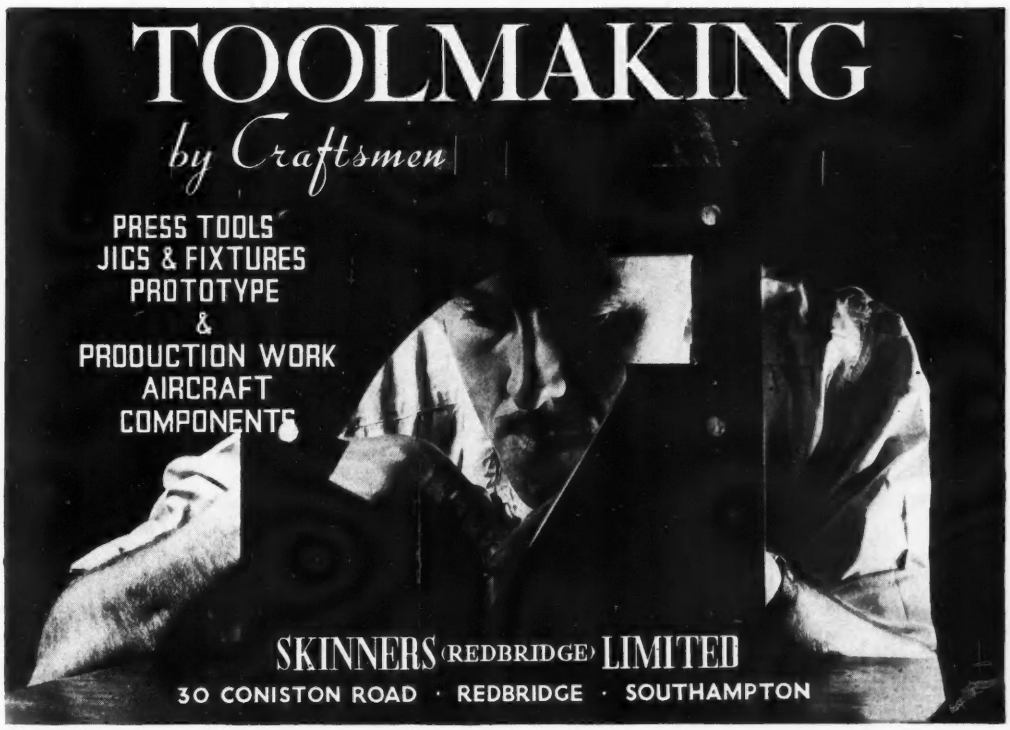

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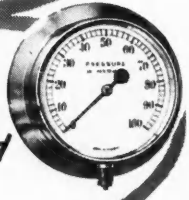

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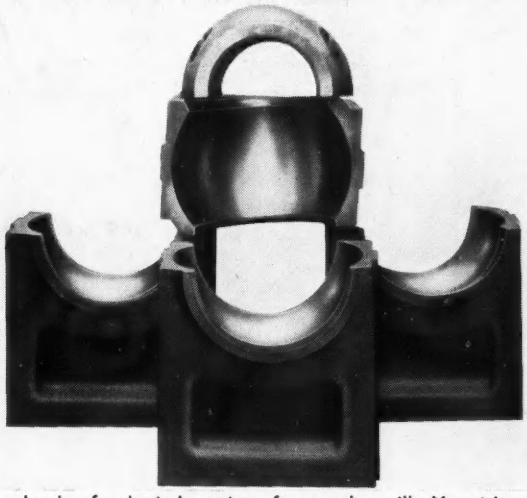

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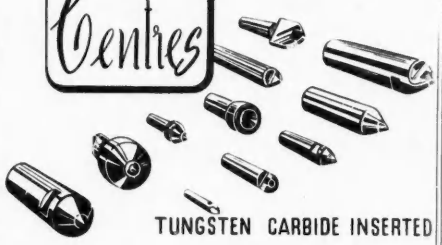

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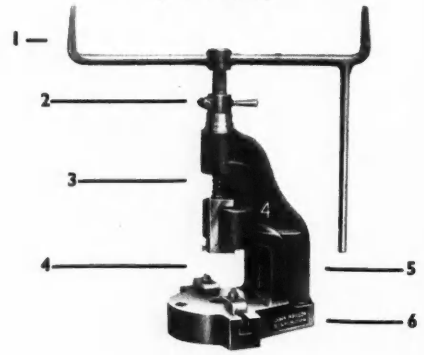

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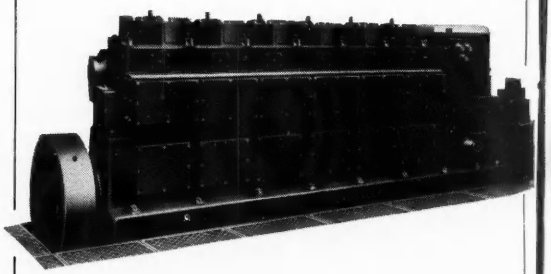

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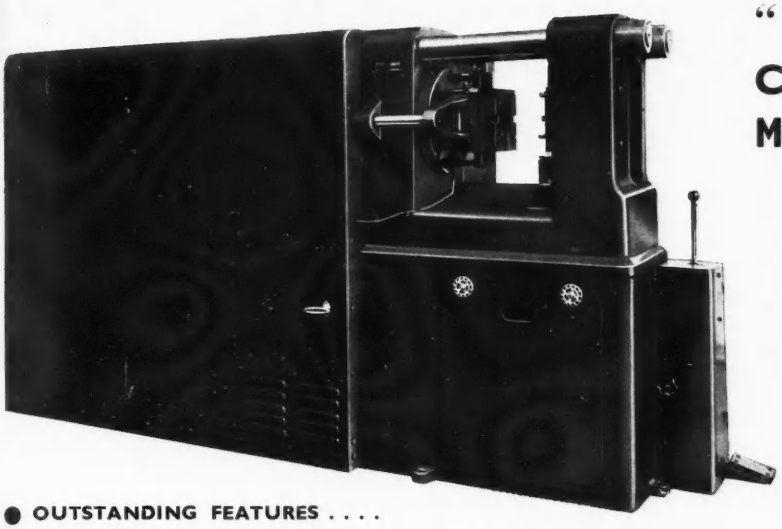

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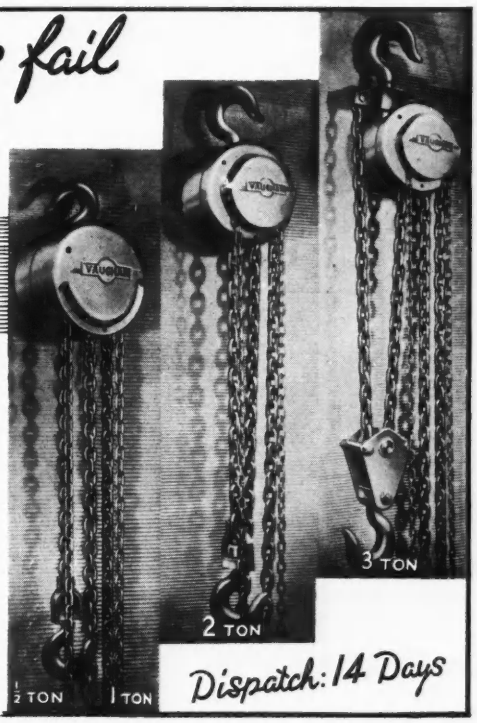

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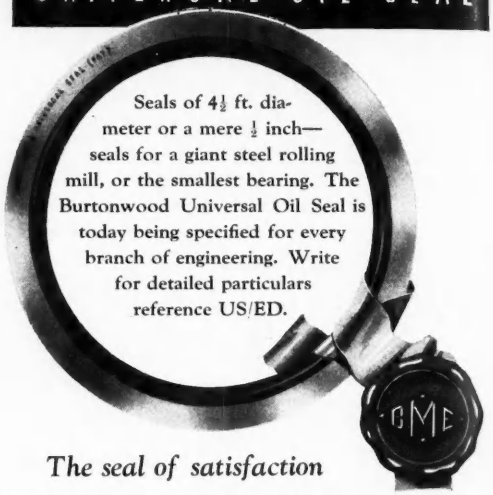
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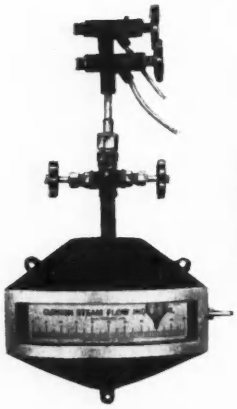

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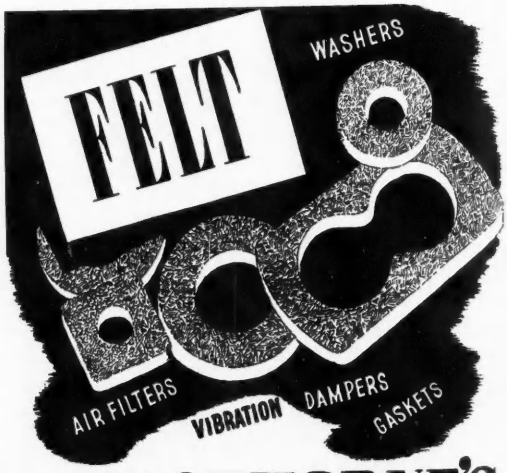

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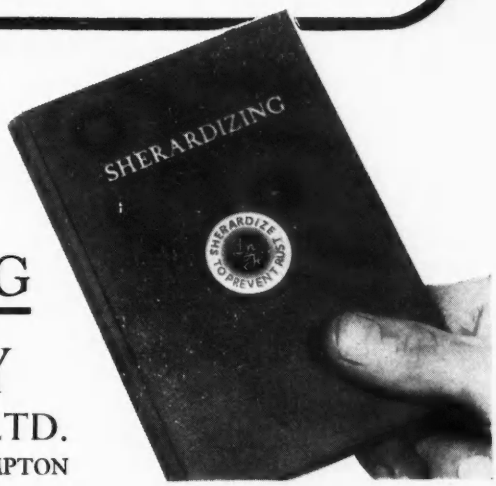

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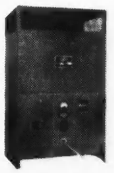

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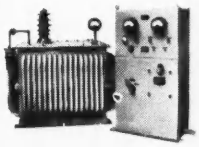

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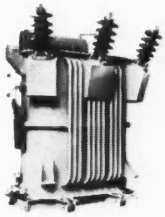

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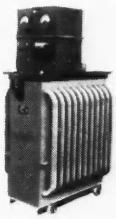

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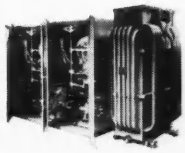

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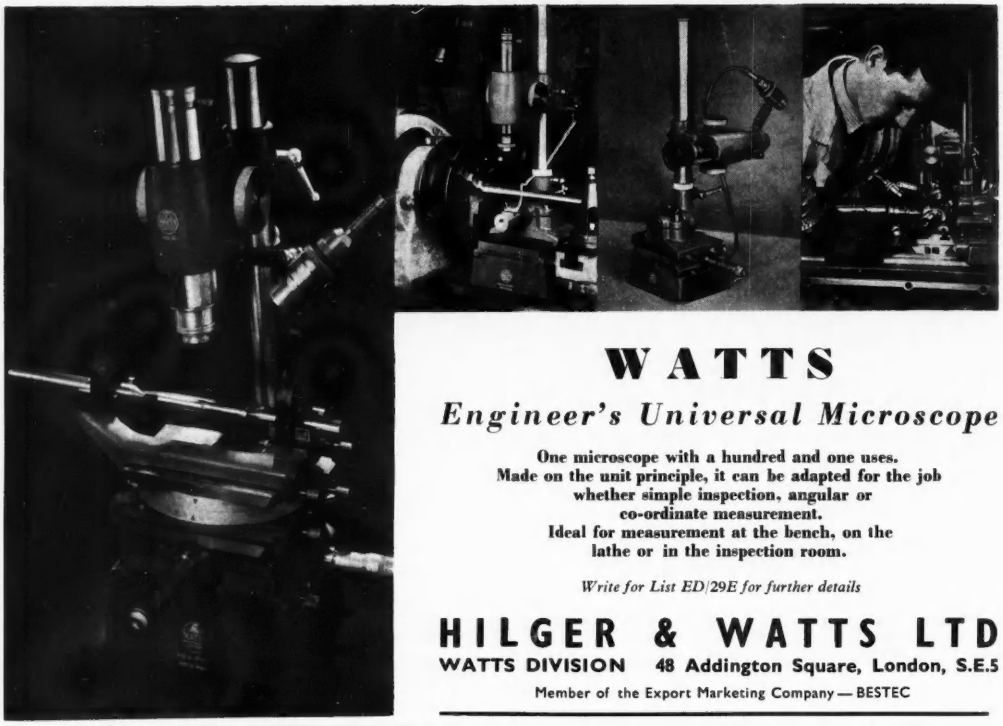

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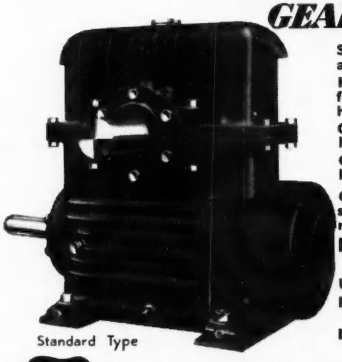

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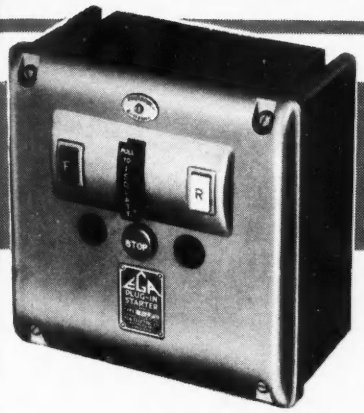
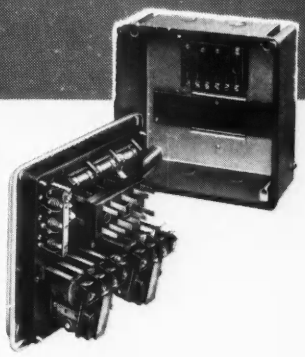
EGA PLUG-IN MOTOR CONTROL GEAR



The PLUG-IN REVERSING STARTER



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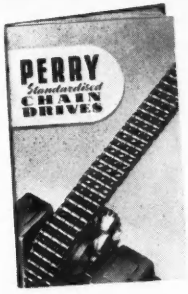

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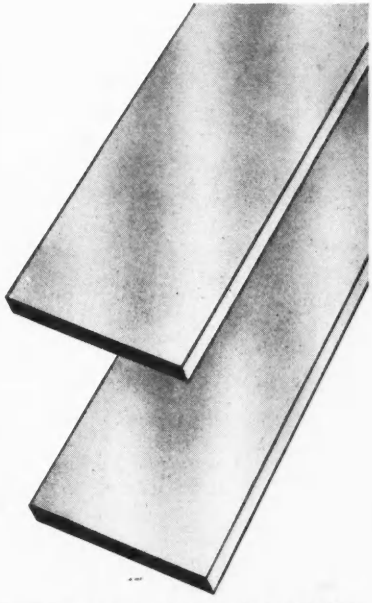

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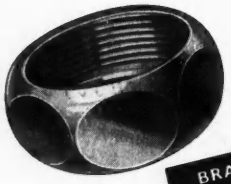

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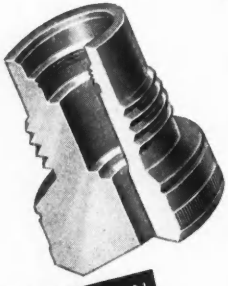

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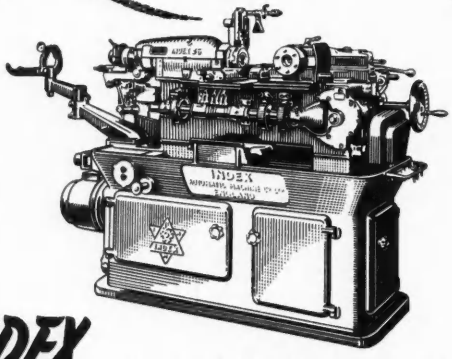

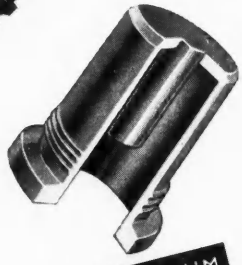

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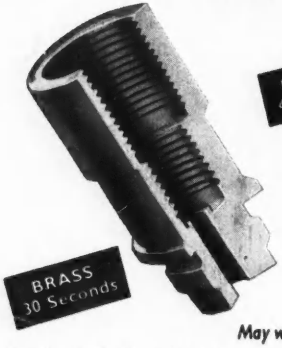

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